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16. ABSTRACT

Two strategic approaches to water quality control in Oregon's Willamette River are presently being utilized: point source treatment and flow augmentation from reservoirs. Input/Output analysis (I/O) provides an econometric methodology to study direct and indirect energy response to pollution control alternatives. An energy I/O national model is coupled with a comprehensive Willamette River dissolved oxygen model. Three approaches to environmental control for the Willamette are examined. One is that of current enforcement coupled with present levels of augmentation. Another consists of less augmentation and increased wastewater treatment. The third approach consists of increased flow augmentation for water quality control. Corresponding treatment is somewhat relaxed. Each alternative of environmental control is evaluated as if it had been practiced in a study year of low natural runoff. The relation of augmentation for water quality to other river uses is used to value flow in a benefits-foregone manner. Independently, reservoir costs are allocated to water quality. For alternatives of treatment and augmentation, river quality, dollar cost and energy impact response surfaces are developed. Indirect energy costs are roughly twice the direct energy use. Energy impact is substantially a reflection of treatment degree. Energy- and dollar-efficient management calls for the full role of augmentation in water quality control.

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September 1978

ECONOMIC AND ENERGY ANALYSES OF REGIONAL WATER POLLUTION CONTROL

by

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FOREWORD

As environmental controls become more costly to implement and the penalties of judgment errors become more severe, environmental quality management requires more efficient analytical tools based on greater knowledge of the environmental phenomena to be managed. As part of this Laboratory's research on the occurrence, movement, transformation, impact, and control of environmental contaminants, the Technology Development and Applications Branch develops management or engineering tools to help pollution control officials achieve water quality goals through watershed management.

The cleanup of the Willamette River represents a case history of successful regional environmental management based on cooperation between industries and local, state, and Federal governments. In this report, the Willamette Basin is used in a retrospective evaluation of the environmental, economic, and energy consequences of alternative strategies for water pollution control. The investigation serves as a planning example for those concerned with environmental management as environmental quality goals increasingly compete with economic and energy objectives.

David W. Duttweiler
Director
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ABSTRACT

Two strategic approaches to water quality control in Oregon's Willamette River are presently being utilized: point source treatment and flow augmentation. Dry weather releases from reservoirs are for authorized purposes other than water quality. However, reservoirs can participate in pollution control by summer flow augmentation if authorized water resource objectives (flood control, navigation, etc.) are not sacrificed.

It is hypothesized that the differences in economic and total energy impacts between treatment and augmentation may be substantial. Of additional interest is the comparison between direct utilization of energy for Willamette Valley pollution control and indirect energy requirements of such programs. Input/output analysis (I/O) provides an econometric methodology to study economic impacts and direct and indirect energy response to pollution control alternatives. In this study, discharge and loadings are empirically related to surveyed direct dollar and energy expenses. An energy I/O national model is coupled with a comprehensive Willamette River dissolved oxygen model. Costs estimated for discharges resulting from different pollution control strategies are then transformed by I/O to total energy costs.

Three approaches to environmental control for the Willamette were examined. One was that of current enforcement coupled with present levels of augmentation. Another consisted of less augmentation and increased wastewater treatment. Appropriate tactics involved advanced secondary methods of treatment, regionalization of treatment plants, and yet more stringent effluent requirements for industry. The third approach consisted of increased flow augmentation for water quality control. Corresponding treatment was somewhat relaxed. Each alternative of environmental control was evaluated as if it had been practiced in a study year of low natural runoff.

The relation of augmentation for water quality to other river uses was utilized to value flow in a benefits-foregone manner. Independently, reservoir costs were allocated to water quality. An instream unit price was thus assigned to augmentation.

For each alternative of treatment and augmentation, the dissolved oxygen quality of the Willamette was simulated and the costs of the environmental strategy estimated. River quality, dollar cost, and energy impact response surfaces were developed. Indirect energy costs, largely expended out of the region, were roughly twice the direct energy use.

Because of the predominance of treatment expenses over augmentation cost and the energy-intensive nature of treatment, energy impact was substantially a reflection of treatment degree. Because augmentation reduced treatment required, energy and dollar efficient management calls for the full role of augmentation in water quality control. In some degree this presently occurs.

Policies of the region were compared; the present commitments to environmental improvement and economic development were found to contradict the area's energy objectives.

This report was submitted in fulfillment of Contract Number 68-03-2397 by Oregon State University, Water Resources Research Institute under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period April 1, 1976, to July 31, 1977, and work was completed as of April 1978.

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SECTION I

INTRODUCTION

BACKGROUND

The decline in water quality of Oregon's Willamette River and its subsequent restoration have been well documented, both in technical and popular literature (1,2). By 1938 industrial and municipal wastewater discharges in the Willamette Basin had resulted in deterioration of the quality of the Willamette River. During summers, critically low dissolved oxygen concentrations had drastically affected fish migration, aesthetics, and recreation. High fecal bacteria concentrations, floating and benthic sludges, sulfur odors, and infestations of the filamentous bacteria Sphaerotilus had become prevalent.

The State of Oregon through the Oregon State Sanitary Authority (OSSA) began policies in the 1950's to improve water quality on the Willamette River. In 1949 only two primary wastewater plants were completed in the Valley. However, by 1957 all Willamette main stem dischargers except Portland practiced primary treatment. In this same period, the pulp and paper mills had greatly reduced their summer discharges of sulfite waste liquor through lagooning of summer flows, barging to the Columbia, and recovering various byproducts.

In the late 1950's, OSSA began to encourage secondary municipal wastewater treatment. Plants contributing wastes to the most polluted reaches of the river were the first to be upgraded. By the mid-1960's all Willamette Basin municipalities had secondary treatment facilities. Likewise, most industries had improved their effluents to secondary quality by this time.

During the 1950's and 1960's several multipurpose reservoirs were constructed by the U. S. Army Corps of Engineers on the upper Willamette tributaries. Annual drawdown of these facilities significantly augmented the Willamette's summer low flows. As a result, wastes were diluted and transported more rapidly out of the Basin.

Today, the Willamette is noted for its high water quality that was achieved by effective, wide-spread pollution control. The river's cleanup provides a rare case history of successful regional environmental management. Cooperative regulation between industries and local, State, and Federal governments restored the quality of this river in an era when environmental protection was not a popular cause. Because of the general understanding of the recovery of the Willamette River, this river provides a setting in which alternative methods of pollution control can be compared. Various methods of water quality control can be hypothetically proposed, simulated with mathematical modeling, and tested for effectiveness.

It is increasingly recognized that environmental quality is a goal competitive with portions of economic and energy objectives. The three issues, environment, economy, and energy, should be considered simultaneously in a planning process. Whereas the Willamette River has served well as a how-to-cleanup demonstration, its use as a planning example today requires the inclusion of economic and energy dimensions.

In an earlier study of the Willamette River (3), data were compiled dealing with the energy costs of the pollution control techniques applied to the Willamette. Capital and operational costs involved in the cleanup were determined from documents and survey questionnaires. From that work, the total energy consumption for pollution control was estimated and a general understanding emerged of the dollar and energy costs for Willamette water quality control.

STUDY OBJECTIVES

This study extends this earlier work (3), which was an energy and economic inventory, to an economic and energy comparison of water pollution control alternatives. Oregon's environmental, economic, and energy policies are briefly discussed. The environmental, economic, and energy impacts of different approaches to water pollution control on the Willamette River are simulated and compared.

Five objectives are pursued dealing with technical impacts of water pollution control alternatives in the Willamette Basin. They are:

1. To select a representative water quality parameter that can serve as a sensitive indicator of the environmental conditions of the Willamette River;
2. To use this selected water quality parameter to develop a river water quality simulation model;
3. To use the model to quantify the relative environmental effectiveness of each of three water pollution control strategies: the applied strategy of secondary point source treatment and low flow regulation from Federal reservoirs, a strategy directed toward increased treatment, and a strategy directed toward greater reliance on flow augmentation. Each strategy was evaluated for the conditions of 1973, a base year discussed later in this chapter;
4. To estimate the economic cost of attaining several levels of water quality under each strategy; and
5. To estimate the energy cost by Input/Output analysis associated with each strategy and water quality level.

These tasks deal objectively with a real issue of environmental-economic-energy interplay, but the issue also has subjective planning implications. Thus, two additional objectives are pursued, not as technical issues, but to provide this broader perspective. They are:

6. To identify major Oregon policies dealing with its state-wide environment, economy, and energetics; and
7. To relate the impacts of the three general strategies of pollution control to these policies.

STUDY DESIGN

Figure 1 illustrates the general procedure of investigation. Roman numerals refer to sections of this report. Parenthetical numbers refer to the study objectives previously listed.

Sections IV and V are of a broad, background nature. These water resources discussions focus on various aspects of Willamette Basin hydrology and development. Later sections on environmental and economic modeling draw from this material. The policies discussed in Section V center on Oregon's environmental, economic and energy goals from which strategies of pollution are ultimately judged.

Environmental, economic, and energy models that are useful for testing and comparing the pollution control strategies are developed in Sections VI, VII and VIII. The first part of each chapter deals with model selection; the remainder deals with model specification.

Section IX, "Analysis," deals with the systematic application of the three models to alternatives for pollution control. In this chapter, the entire technical analysis is traced from identification of pollution control strategy to environmental, economic, and energy impacts.

Section IX draws together the application of the analytical models. Section X relates modeled results to policies established by the State. Section IX is technical, whereas Section X deals with more general implications for comprehensive environmental decision-making.

THE STUDY YEAR

The year 1973 marked a significant point in Willamette water pollution control. Most of the pollution control before this year resulted in water quality improvement. Environmental regulation after this period has been directed toward anticipated future growth. Until 1973, most pollution treatment was achieved by secondary wastewater plants and their industrial equivalents. Costs for such control can be estimated with reasonable accuracy. Sensitivity of both water quality and economic cost to the pollution control strategy allowed strategic alternatives to be compared for this year.

August 1973 illustrates critical hydrologic conditions brought on by a 25-year-low summer flow. Reservoirs were effectively used to maintain aerobic river quality suitable for fish migration. The value of the augmentation can be estimated from realized, not supposed, water quality conditions. Data gathered by the U.S. Geological Survey plus records of Oregon's Department of Environmental Quality (DEQ, successor to the OSSA) independently documented this period.

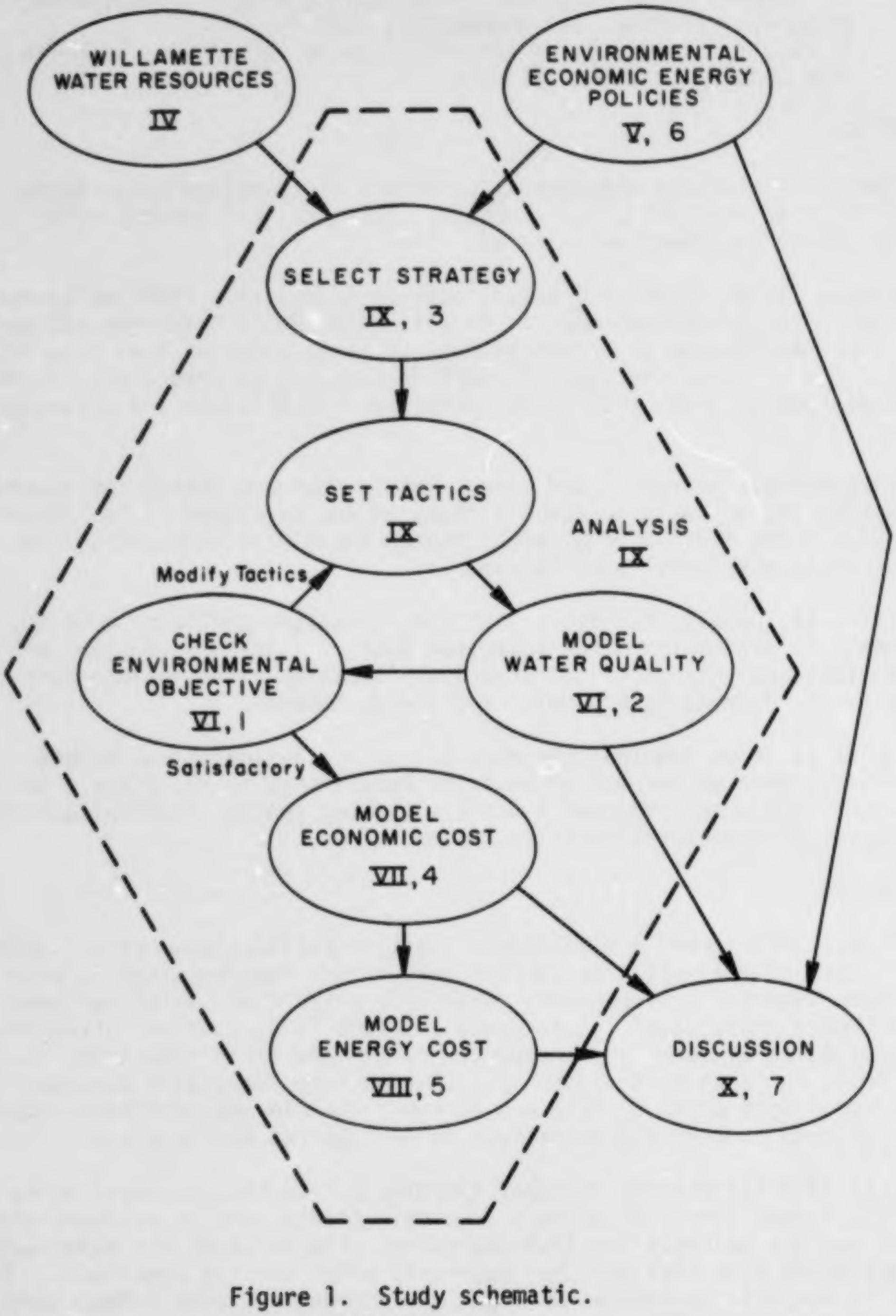
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Figure 1. Study schematic.

This study deals with alternative ways in which 1973 conditions could have been managed. For example, flows from reservoirs could have been increased or decreased. Construction of wastewater treatment facilities before 1973 could have been accelerated, achieving higher waste removal, or could have proceeded less rapidly, accomplishing somewhat less point source treatment by 1973. These are the trade-offs that are examined in this study for the Willamette River.

This study is not a projection in time. Some likelihoods about the future might be summarized from the analysis, but extrapolations, at best, should be done with caution. The best employment of this study is that of retrospective analysis. The relationship of energy to dollars illustrates the dual price paid for pollution management. The relationship of both these costs to environmental consequences illustrates returns from investments. The dollar and energy relationships between tactics of environmental control illustrate the sensitivity of environmental quality to pollution control methods.

SECTION II

CONCLUSIONS

The two-pronged strategy of water quality control has restored the environmental quality of Oregon's Willamette River to a well-oxygenated waterway that supports anadromous fish. This strategy employed abatement of municipal and industrial discharges and increased low flow augmentation from Federal reservoirs. The Willamette River presently provides Oregon's residents with a variety of services possible from the preservation of its natural resources. It is a prime State concern that the high environmental quality on the Willamette is maintained. Whereas the Willamette was restored at a dollar cost that Oregonians were willing to pay, the energy investment was considered little in the decision-making process.

This investigation examined the environmental, economic, and energy consequences of various strategies for environmental management. These strategies considered varying degrees of both point source treatment and low flow augmentation. Based on this study, the following conclusions were reached.

1. Water quality control in the Willamette Basin was estimated to have cost $33 million annually in 1973. Of this total, $6 million was spent to divert and treat the Basin's wastewaters to outfalls other than on the Willamette, $3 million represented the water quality benefits of low flow augmentation, and $12 million was spent by the industrial and by the municipal sectors, respectively, for treatment. Of the $30 million spent for waste treatment, $8 million was used for operation, maintenance, and replacement (OMR) and $22 million was the annualized portion of capital costs.

2. The use of existing reservoirs for high, but not maximized, releases for water quality protection represented a reasonably cost effective environmental strategy. Depending upon the method of assigning costs of flow augmentation, savings of $2 to $4 million per year might have occurred if augmentation from existing reservoirs had been increased and offsetting treatment investment foregone. However, if the reservoirs had not been employed, an additional $7 million annually would have been required for treatment to have achieved the 1973 low flow dissolved oxygen quality.

3. Low flow augmentation was particularly effective in maintaining summertime dissolved oxygen (DO) in the Willamette River. Some specific advanced secondary tactics may exist that would benefit summertime DO quality more effectively than maximized augmentation if reservoir releases had large alternative value for irrigation. If wastewaters had been treated in 1973 at advanced levels, augmentation from existing reservoirs should have been maximized for summertime DO quality for any reasonable price of augmentation waters.

4. A unit price of \$3/af (acre-foot, 1233 m^3) for summer releases from reservoirs reasonably approximated the value of that water for pollution control if water quality was measured by summertime, 25-year low flow DO levels. Thus, if waters were valued for irrigation at less than \$3/af, greater benefits would result if the flows were left instream to dilute wastes and to decrease river travel time. If reservoir releases diverted to agriculture are valued at \$20/af, maximum net benefit to the Willamette Basin would occur with maximum use of secondary waste treatment and with only natural river discharges.

5. In 1973, 510 TJ (terajoule, 948 x 10^6 Btu) of direct energy were consumed for Willamette pollution control. Direct energy is defined as the fossil fuel equivalent of fuels and electricity consumed at the site for point source control or flow agumentation. The reservoir costs associated with water quality benefits, which were allocated by savings in year-around point source facilities to control summertime DO, were 37 TJ. Of the 473 TJ used for treatment, 86 were used to halt discharges to the Willamette and 387 were used to treat discharges. Industrial pollution control required 166 TJ and municipalities required 307 TJ. For pollution control, 363 TJ were consumed in operation and 147 TJ represented the fuels used for annualized construction. Energy use for water pollution control in the Willamette Valley accounted for 0.1 to 0.2 percent of the regional direct energy consumption.

6. In 1973, 1373 primary TJ were required to directly and indirectly support Willamette pollution regulation. This primary energy value is the fossil fuel requirement of the economy to produce both the direct energy and the materials consumed. Primary energy does not incorporate many energy consequences of pollution control, such as the changed productivity of a valley inundated by a reservoir or a forest harvested to foster economic production to pay for pollution control. Primary energy, which is defined in terms of fuels mined from the earth, is the more traditional planning parameter. The reservoirs' share of this primary total was 120 TJ. Of the 1253 TJ needed for treatment tactics, 515 TJ were used by industries and 738 TJ by municipalities.

7. Dollar-to-energy coefficients derived from Input/Output analysis varied with pollution control activities. Treatment plant construction typically used 0.8 times as many direct joules per dollar as reservoir construction, but 1.4 times as many primary joules. Treatment plant OMR used 3.2 times as much direct energy per dollar as did reservoir OMR. Plant OMR required 2.9 times as much total energy per dollar as did reservoirs.

8. For every unit of direct energy consumed in Willamette pollution control, approximately an additional 1.7 units were consumed indirectly. Thus for a typical pollution control activity consuming 10 TJ of energy at the site (7 TJ to build the facility and another 3 TJ for OMR, for example), an additional 17 TJ were consumed for the required construction and operation materials. The primary energy cost for this activity would be 27 TJ. The ratio of indirect and direct estimates varied with activities. For construction of treatment plants it was nearly 5.0; for OMR, 0.7. For construction and OMR of reservoirs, the ratios were 2.3 and 0.9, respectively.

9. Although Input/Output energy analysis improves the scope of environmental decisions over those based solely on dollars, it does not appear that this energy analysis gives results substantially different than dollar-valued conclusions. This conclusion stemmed from the strong dependence of energy Input/Output expressions upon dollar data.

10. Energy costs, like dollar costs, were shown to substantially vary with environmental strategy. Of particular relevance in a time of primary energy scarcity is the prediction that energy requirements could double for pollution control if higher-than-secondary wastewater treatment was required uniformly.

11. Oregon's environmental, economic, and energy policies are not entirely reconciled with one another. The restoration of the Willamette's DO was in harmony with environmental policies. The dollar expense for this cleanup was willingly paid by Oregonians and the net effect was an immediate economic advantage to the Basin. The energy costs required for water pollution control, however, were drains on fossil reserves for the Basin's economy. Summertime DO was purchased with fossil fuels likely needed for long-term economic growth.

SECTION III

RECOMMENDATIONS

METHODOLOGICAL RECOMMENDATIONS

1. Energy analysis of alternative environmental strategies is most likely to bring new perspective to decision making if the alternatives are selected so that equivalent environmental states have substantially different energy requirements. Such a method identifies energy-efficient environmental control, but does not impose a technical solution on the tradeoffs between energy and environmental quality.

2. Energy analysis of public decisions may be undertaken in direct and/or primary terms. In a region where local supply of energy is limited, but extraregional energy supply is great, analysis should center on direct energy requirements. In a region where energy may be imported as needed, but where the stock for imports is being exhausted, energy analysis should be in primary units. In a region where there is local competition for energy and where the total energy stock is being reduced, analyses should include both measure of energy.

3. Input/Output energy analysis is inappropriate when rapidly changing economic organization and technology occurs. In this study, effort was made to establish study bounds close to actual, documented conditions. Input/Output models should not be employed in investigations where verification is unsubstantiated.

4. Input/Output energy analysis should be employed to distinguish between planning strategies only when the alternatives represent substantially different predominant tactics and those tactics are of significantly different energy impacts. Input/Output energy analysis should not be employed to distinguish between strategies differentiated only by tradeoff of one tactic and the environment since the same analysis can be made more directly in dollar terms.

5. Energy and economic Input/Output analysis of regional environmental issues may use nationally based data if regional disconformity is shown to be minor in the sectors of direct interest. The alternative approach of developing a complete and unique regional I/O data base is likely to be too data-sparse for planning purposes.

6. Studies employing Input/Output models must properly conform economic activities of interest with sectors established for the model. Pollution control exemplifies an activity that is not readily expressed as an explicit

economic endeavor, but rather must be approximated by several, more general I/O sectors.

7. River modeling should emphasize simple expressions, data suited to the modeling enterprise, and familiarity with the problem. Complex models built upon data taken for other objectives are likely to be of little value to the decision maker.

POLLUTION CONTROL RECOMMENDATIONS

8. Water quality planners for the Willamette should adopt a water quality model that they themselves can evaluate and modify.

9. Federal reservoir cost allocation procedures should afford full credit for water quality improvement to multipurpose water resource projects. In such a way, environmental control may be made more cost-effective. In lieu of a reallocation of existing Willamette projects, a unit price of $3/af should be assigned to reservoir releases for late summer flow augmentation where summertime DO is the environmental objective and alternative points source control tactics call for advanced secondary treatment operated on a year-around basis. This unit price is not proposed for the evaluation of additional reservoir capacity since the marginal returns of new construction should be evaluated only after existing facilities are efficiently operated.

10. Willamette DO standards should be evaluated in terms of both regional and national dollar and energy costs.

11. If low flow Willamette augmentation is used efficiently with wastewater treatment, eventually the upper limit of augmentation from existing reservoirs will be required. Water pollution control strategies that propose increased wastewater treatment and source control should be implemented only if the option to increase augmentation is foregone.

12. Public policies that overlap should be analytically reconciled where possible. Environmental, economic, and energy policies for the Willamette Basin serve as an example. The present environmental and economic policies tend to nullify the energy objectives. An alternative policy perspective is needed from which the policies in harmony with each other, with human welfare, and with nature might be selected.

SECTION IV

WATER RESOURCES

INTRODUCTION

The abundant natural resources of Oregon's Willamette River Basin have made possible the Valley's rapid economic development. The Willamette's waters provide Valley residents with substantial water services including municipal, industrial, and agricultural water supply; navigation; hydroelectric power; flood control; recreation; waste disposal; and fish and wildlife habitat. The Willamette Basin is today one of the few regions in the United States where economic growth, water resource development, and environmental considerations have proven to be reasonably complementary.

This section provides an overview of the Willamette Basin and describes the present-day character of water resource development.

PHYSICAL SETTING

General Physiography, Geology, and Hydrology

The Willamette Basin (Figure 2) is bounded on the east by the Cascade Mountains, on the west by Oregon's Coast Range, on the south by the Umpqua Basin, and on the north by the Columbia River into which the Willamette flows at Portland. The area of the Willamette Basin is 29,687 square kilometers (km^2), 31 percent of the state total. Approximately 70 percent of the land is forest and 30 percent is in agricultural production. Only 5 percent is urbanized.

The Basin may be divided physiographically into four sectors: the Coast Range, the northern Valley, the southern Valley, and the Cascades. The Cascades can be further divided into the lower-lying western Cascades and the rugged, snowcapped High Cascades (4).

The Coast Range has a crestline rising to 1249 meters (m) and extends to the Pacific shore. Orographic precipitation from prevailing Pacific westerlies feeds short, steep sediment-laden coastal streams. Because the range is typically low (<500 m) and the westerlies humid and persistently strong, much precipitation which is condensed in the westerly upwelling is carried over the Coast Range. The readily available rainfall (typically 1.5 m per year) on both sides of the Coast Range far exceeds local water requirements except during the rarest droughts.

The Willamette Valley floor is divided physiographically by the Salem-Eola Hills. North of these hills, the Valley is composed of non-marine sedi-

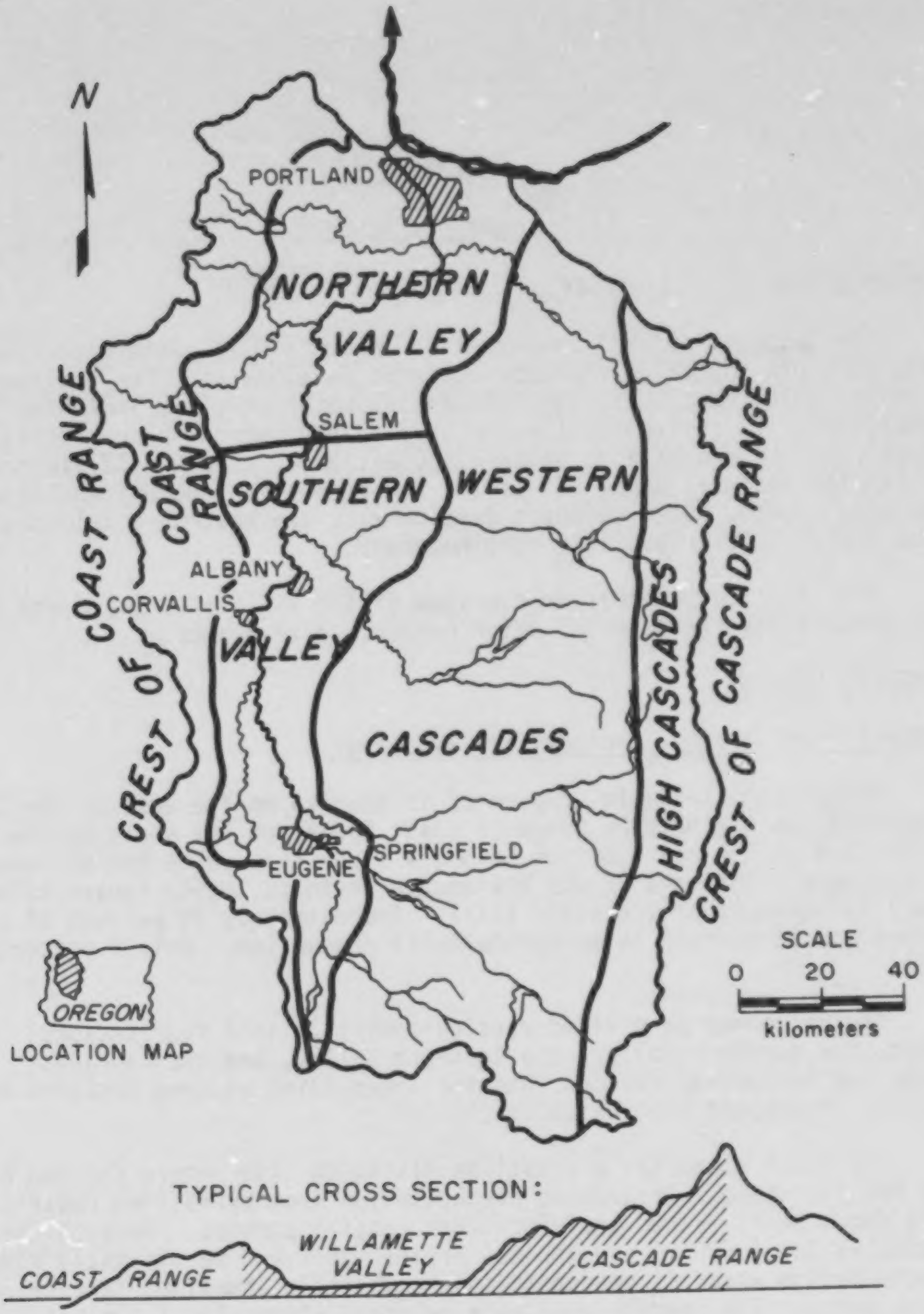

N
PORTLAND
NORTHERN
VALLEY
SALEM
SOUTHERN
VALLEY
WESTERN
CASCADES
COAST RANGE
CREST OF COAST RANGE
HIGH CASCADES
CREST OF CASCADE RANGE
ALBANY
CORVALLIS
SPRINGFIELD
EUGENE
SCALE
0 20 40
kilometers
OREGON
LOCATION MAP
TYPICAL CROSS SECTION:
COAST RANGE
WILLAMETTE VALLEY
CASCADE RANGE

Figure 2. Willamette Basin physiographic sectors and typical cross section (4).

ments and conglomerates. In pre-Pleistocene (ice age) times, the portions of the present-day Willamette Valley bordering the Columbia were extensively built up with Columbia aluvium. At the same time the Willamette, as a lake extending over much of today's Basin floor, deposited a 15 to 30 m bed of sediments. With ice-age sea recession, the lake drained and channels began downcutting and meandering over the alluvial terrace. The northern Valley was again inundated when glacial Lake Missoula broke loose from the Columbia Clark Fork and swept toward the sea 10,000 or 15,000 years ago. The northern Valley has abundant groundwater from the large supply from nearby mountains and the high transmissability due to porous strata of sands and silt.

The southern Willamette Valley floor has experienced similar, but less extensive, sedimentary deposition. Igneous flows and outcrops are common. The southern Valley has redefined its boundaries several times. The Umpqua may have once fed the upper Willamette and the Long Tom may have flowed westward to the Siuslaw and the sea. Gradual weathering of ridges, alluviation, and a rising sea level reduced stream gradients and reoriented channels. Today, the Valley remains broad from Salem to Eugene. Above Eugene a narrow arm of bottom terrain leads up the Coast Fork. As in the north, groundwater is generally available.

Nearly half the Willamette Basin is comprised of the west slope of the Cascades. The Clackamas, Molalla, Santiam, Calapooya, McKenzie, Middle Fork Willamette and Row rivers feed the main stem Willamette from these mountains. The crest line averages somewhat less than 2000 m in altitude with its maximum being 3463 m (Mt. Hood). As the Cascade peaks lie near the eastern boundaries of the mountains, the greater and the wetter portion of the Cascade Range drains west to the Willamette. These western slopes presently support a large timber industry and multiuse Federal and State forests. Slopes are steep, soils are silty-clay, and runoff and infiltration are high.

The High Cascades develop a substantial winter snowpack. Typically the snow is retained until spring when warming temperatures and rain cause rapid melting. Unlike the Columbia, the Willamette snowmelt is completed long before the dry summer months. Even during the dry summer period, however, the discharge of the major Cascade tributaries is substantial.

The Willamette Basin receives abundant rainfall. Fifty percent of the Basin receives 1.5 meters or more of annual precipitation. Seven percent (mountainous regions) experience more than 2.5 m. The driest 1 percent receives 1 m. Runoff is likewise substantial. Fifty percent of the land yields 0.3 meters or less yearly. One percent exceeds 2 m (5). Of the 26 largest rivers in the United States (the Willamette River is fifteenth in annual discharge), the Willamette Basin has the largest runoff/area ratio ($0.03\ m^3/s \cdot km^2$) (6).

The Basin climate is temperature marine. Rain and snow fall during winter and spring; summers and early autumn are clear, dry, and warm. Seventy percent of the annual precipitation occurs from November through March, only about 5 percent during the June-August summer period. The annual range of average monthly temperatures is approximately 14 to 17°C. Extreme daily temperatures for an average winter range from near freezing on the Basin floor to about -8°C in the Cascades. Summer maximums range from approximately 28°C in the Valley to 24°C in the mountains (5).

The Willamette River

The main stem of the Willamette may be divided into three morphological sections as shown in Figure 3. The upstream section, 217 km from Eugene to Newberg, is a relatively steep (0.0005 gradient), braided, shallow (representatively 2 m) erosional regime. Summer velocities are typically 1 meter per second (m/s). From Newberg to the basaltic weir that forms the Willamette Falls (a distance of 41 km), the river is pooled and sluggish. The channel is flatter (0.00001), the depth is greater (7 m), and velocities average approximately 0.2 m/s. Deposition of sediment predominates. Below the Falls (43 km to the Columbia), the river is tidal and during the spring and early summer markedly affected by backwater from the Columbia River. During periods of low Willamette flow, flow reverses twice a day in the lowest reaches which causes water quality in the lowest 8 km to be essentially that of the Columbia River. Depths are maintained at 12 m in the lower 27 km to facilitate navigation. A flat gradient (less than 0.00001) and low velocity (typically 0.1 mps) create a depositional regime (7).

Figure 4 shows inflows to the Willamette for August 1973. Tributaries from the Cascades constitute approximately 90 percent of the summer discharge. Also shown are wastewater discharges.

Thirteen U. S. Army Corps of Engineers reservoirs are located on the southern Willamette Basin tributaries as shown in Table 1 and Figure 5. The reservoirs provide a full pool storage of 2.99 x 10^9 m^3 (2.42 million af). This corresponds to 14 percent of the mean Willamette annual discharge at Salem. As illustrated in Figure 6(a), these reservoirs are operated by draining to low levels to store fall and winter flood flows and storing spring runoff for late summer release. Figure 6(b) shows the corresponding discharge at Salem for 1973 and early 1974.

The marked impact of the reservoirs upon low flow discharge is illustrated in Figure 7, a plot of mean low flows against year. Mass balance analysis of late summer reservoir releases accounts nearly totally for the experienced downstream flow augmentation. Low flows presently are approximately twice the discharge of low flows experienced more than 30 years ago. Figure 7 reveals that hydrologic conditions are typically stable over the low-flow late summer months. The lowest discharge of a single day is not significantly different than the discharge of the driest 30 days.

Basin climate, morphology, and river regulation not only generate characteristic streamflow patterns of the river, but regulate aspects of natural water quality. Precipitation creates high levels of winter turbidity. Eighty percent of the annual sediment load (80 metric tons per square kilometer at Salem) typically is generated from November through February (5). There is relatively little overland runoff or surface erosion during the summer period. Summertime suspended solids concentrations (perhaps 10 mg/l) result in a 2- to 3-meter euphotic zone in the river. This allows the upper section of the main stem to sustain a productive attached population of algae.

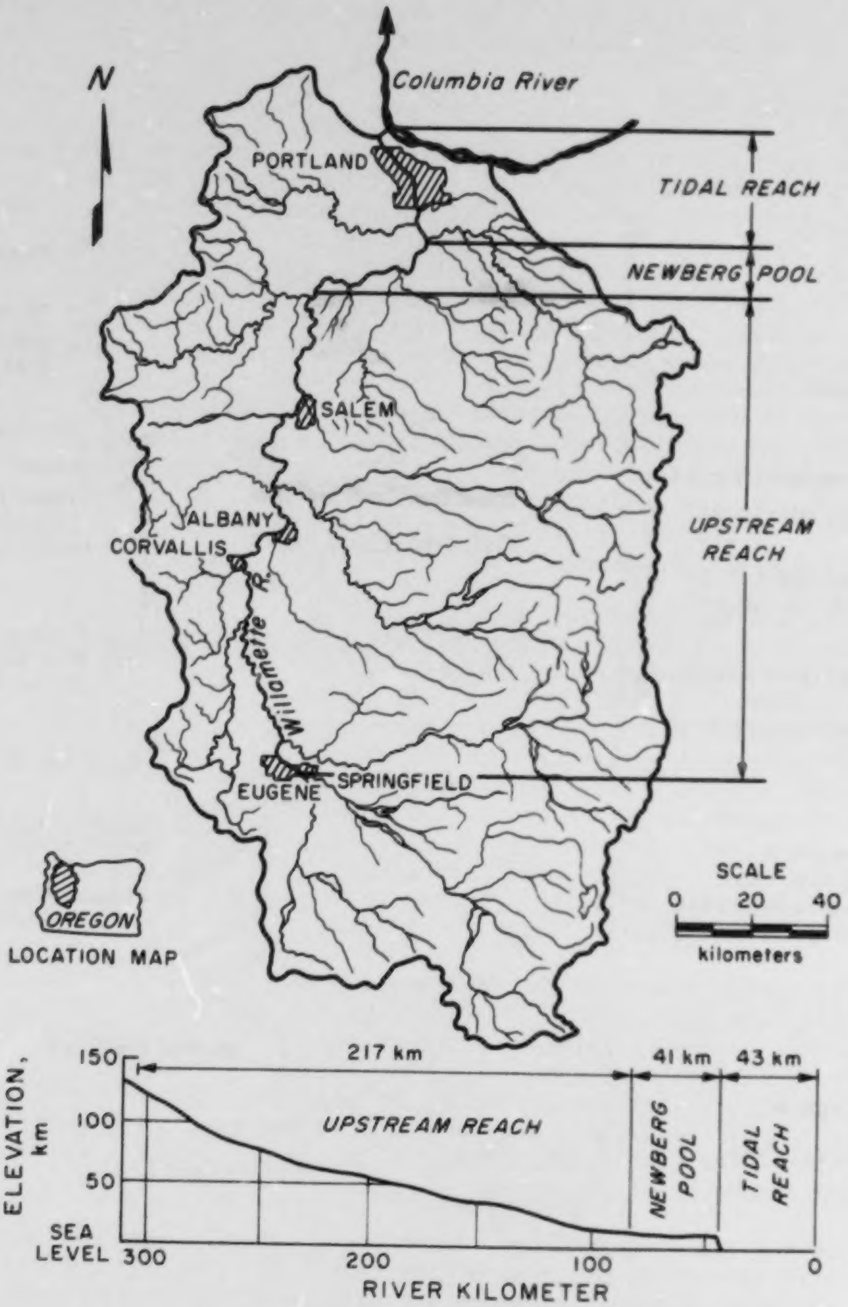
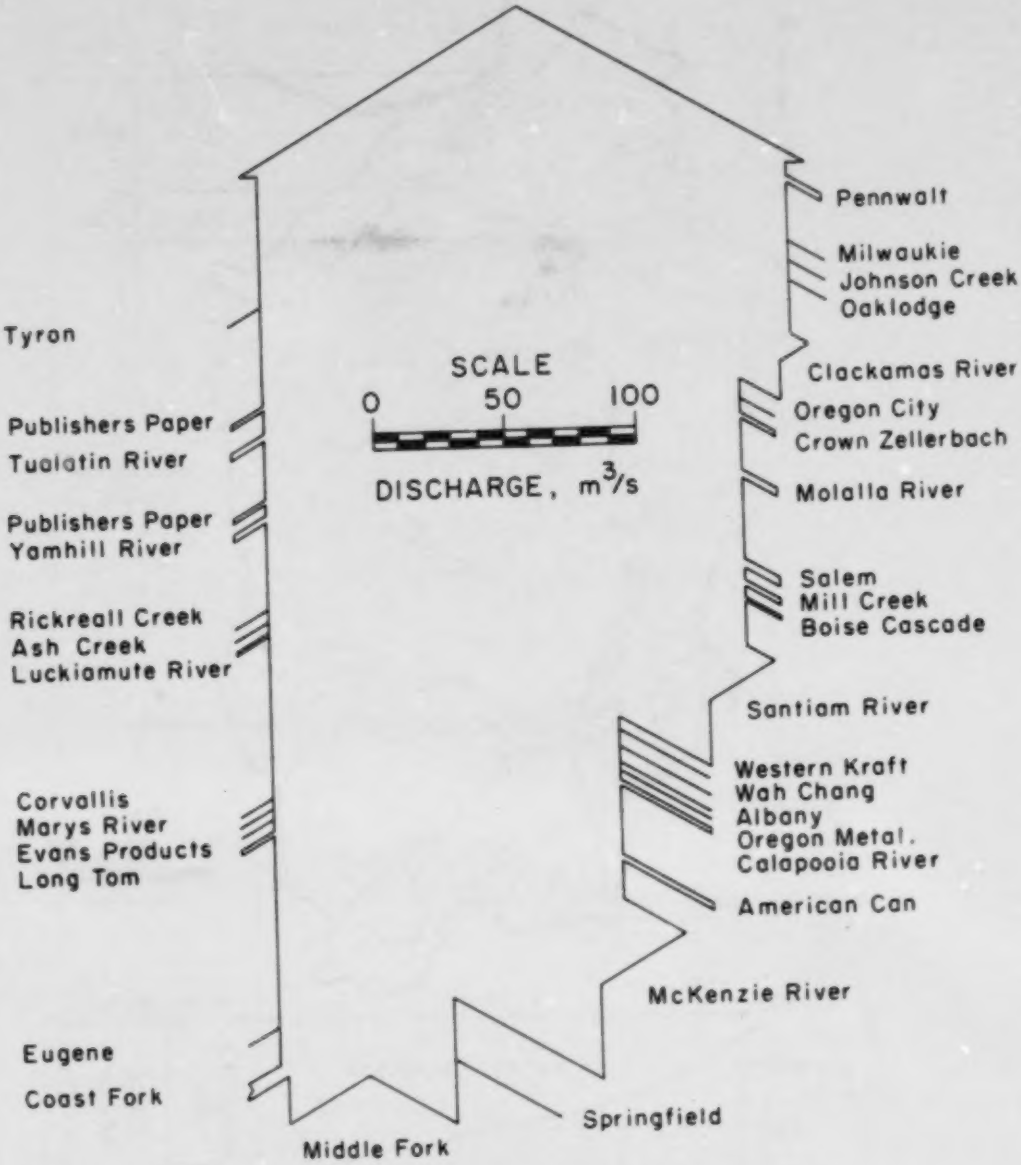

N
Columbia River
PORTLAND
TIDAL REACH
NEWBERG POOL
SALEM
UPSTREAM REACH
ALBANY
CORVALLIS
Willamette R.
EUGENE
SPRINGFIELD
OREGON
LOCATION MAP
SCALE
0 20 40
kilometers
217 km
41 km
43 km
ELEVATION, km
150
100
50
SEA LEVEL
UPSTREAM REACH
NEWBERG POOL
TIDAL REACH
300
200
100
0
RIVER KILOMETER

Figure 3. Willamette River geomorphologic reaches (7).



Pennwalt
Milwaukie
Johnson Creek
Oaklodge
Tyron
SCALE
0
50
100
DISCHARGE, m^3/s
Clackamas River
Oregon City
Crown Zellerbach
Publishers Paper
Tualatin River
Molalla River
Publishers Paper
Yamhill River
Salem
Mill Creek
Boise Cascade
Rickreall Creek
Ash Creek
Luckiamute River
Santiam River
Western Kraft
Wah Chang
Albany
Oregon Metal.
Calapooia River
Corvallis
Marys River
Evans Products
Long Tom
American Can
McKenzie River
Eugene
Coast Fork
Springfield
Middle Fork

Figure 4. Willamette River flow balance, August 1973 (8, 9, 10).

TABLE 1. STORAGE RESERVOIRS IN THE WILLAMETTE BASIN WITH 1 MILLION CUBIC METERS OR MORE OF USABLE STORAGE CAPACITY

Rank	Reservoir name	Stream	Operator*	Year placed in operation	Usable Storage		Authorized purposes†
					10^6 m^3	acre ft.	
1	Lookout Point	Mid Ford Willamette	C of E	1954	431	349 400	FC, N, I, P
2	Detroit	N. Santiam R.	C of E	1953	420	340 000	FC, N, I, P
3	Green Peter	Mid Santiam R.	C of E	1966	411	333 000	FC, N, I, P
4	Hills Creek	Mid Fork Willamette	C of E	1961	307	249 000	FC, N, I, P
5	Cougar	S. Fork McKenzie R.	C of E	1963	204	165 100	FC, N, I, P
6	Fall Creek	Fall Cr.	C of E	1965	142	115 000	FC, N, I
7	Fern Ridge	Long Tom R.	C of E	1941	136	110 000	FC, N, I
8	Blue River	Blue R.	C of E	1968	105	84 000	FC, N, I
9	Dorena	Row R.	C of E	1949	87	70 500	FC, N, I
10	Timothy Lake	Oak Grove Fork	PGE	1956	76	61 650	P, R
11	Scoggins	Scoggins Cr.	BOR	1975	65	53 800	FC, I, M&I R, F&W, WQ
12	Foster	S. Santiam R.	C of E	1966	41	33 600	FC, P
13	Cottage Grove	Coast Fk. Willamette	C of E	1942	38	30 600	FC, N, I
14	Smith	Smith R.	EWEB	1963	12	9 900	P
15	North Fork	Clackmas R.	PGE	1958	7	6 000	P, R
16	Dexter	Mid Fork Willamette	C of E	1954	6	4 800	P
17	Trail Bridge	McKenzie R.	EWEB	1963	3	2 750	P
18	Big Cliff	N. Santiam R.	C of E	1953	3	2 430	P
19	Dallas	Rickreall Cr.	Dallas	1960	1	1 200	M&I

* C of E=Corps of Engineers; PGE=Portland General Electric; EWEB=Eugene Water & Electric Board; Dallas=City of Dallas; BOR=Bureau of Reclamation

† FC=flood control; N=navigation; I=irrigation; P=power; R=recreation; M&I=municipal & industrial; F&W=fish and wildlife; WQ=water quality. All existing Federal reservoirs are used for recreation, even though not so authorized.

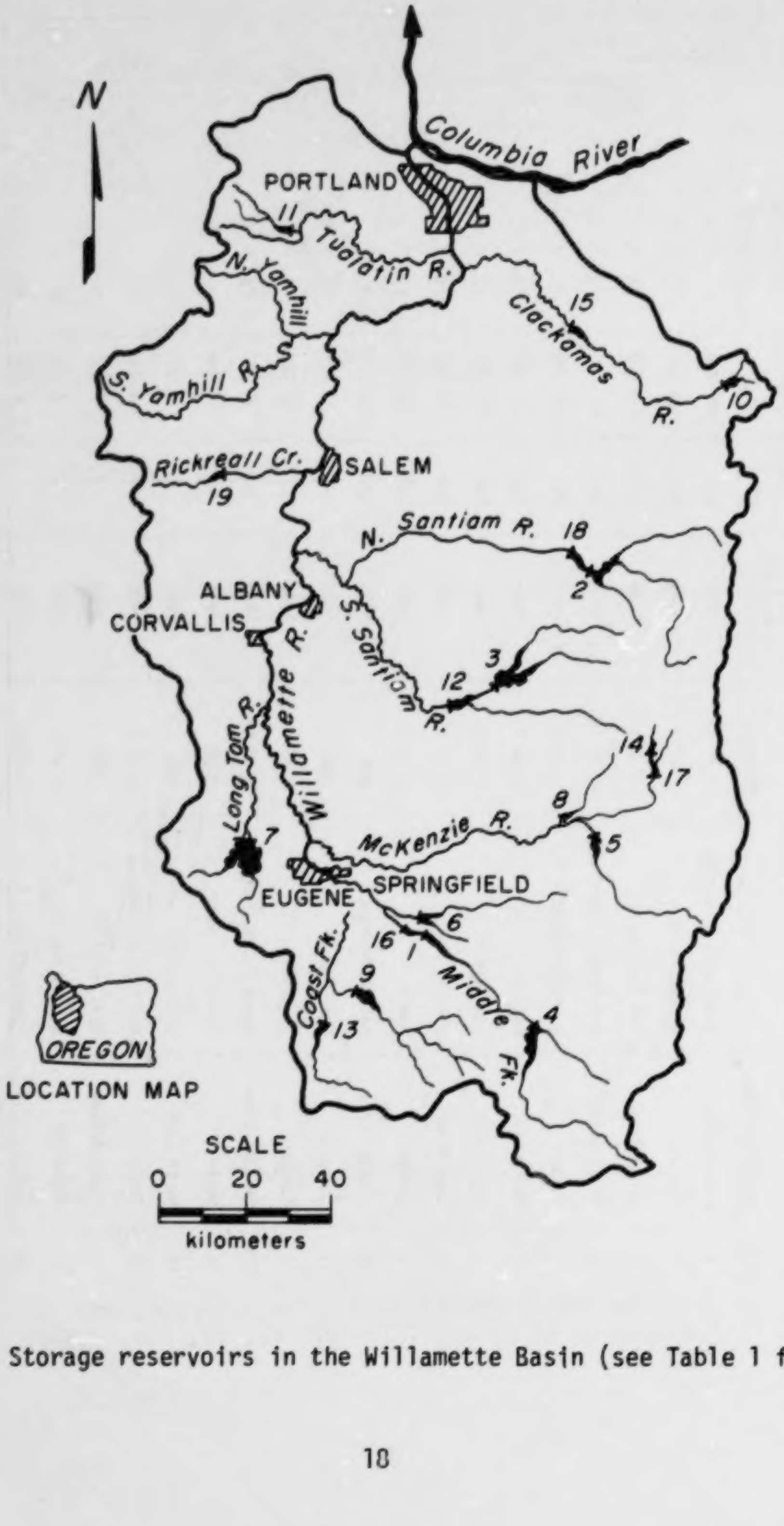

N
Columbia River
PORTLAND
11
Tualatin R.
N. Yamhill
S. Yamhill R.
15
Clackamas R.
10
Rickreall Cr.
19
SALEM
N. Santiam R.
18
2
ALBANY
CORVALLIS
S. Santiam R.
3
12
Willamette R.
Long Tom R.
14
17
8
McKenzie R.
5
7
EUGENE
SPRINGFIELD
6
16
1
Coast Fk.
9
13
Middle Fk.
4
OREGON
LOCATION MAP
SCALE
0
20
40
kilometers

Figure 5. Storage reservoirs in the Willamette Basin (see Table 1 for key).

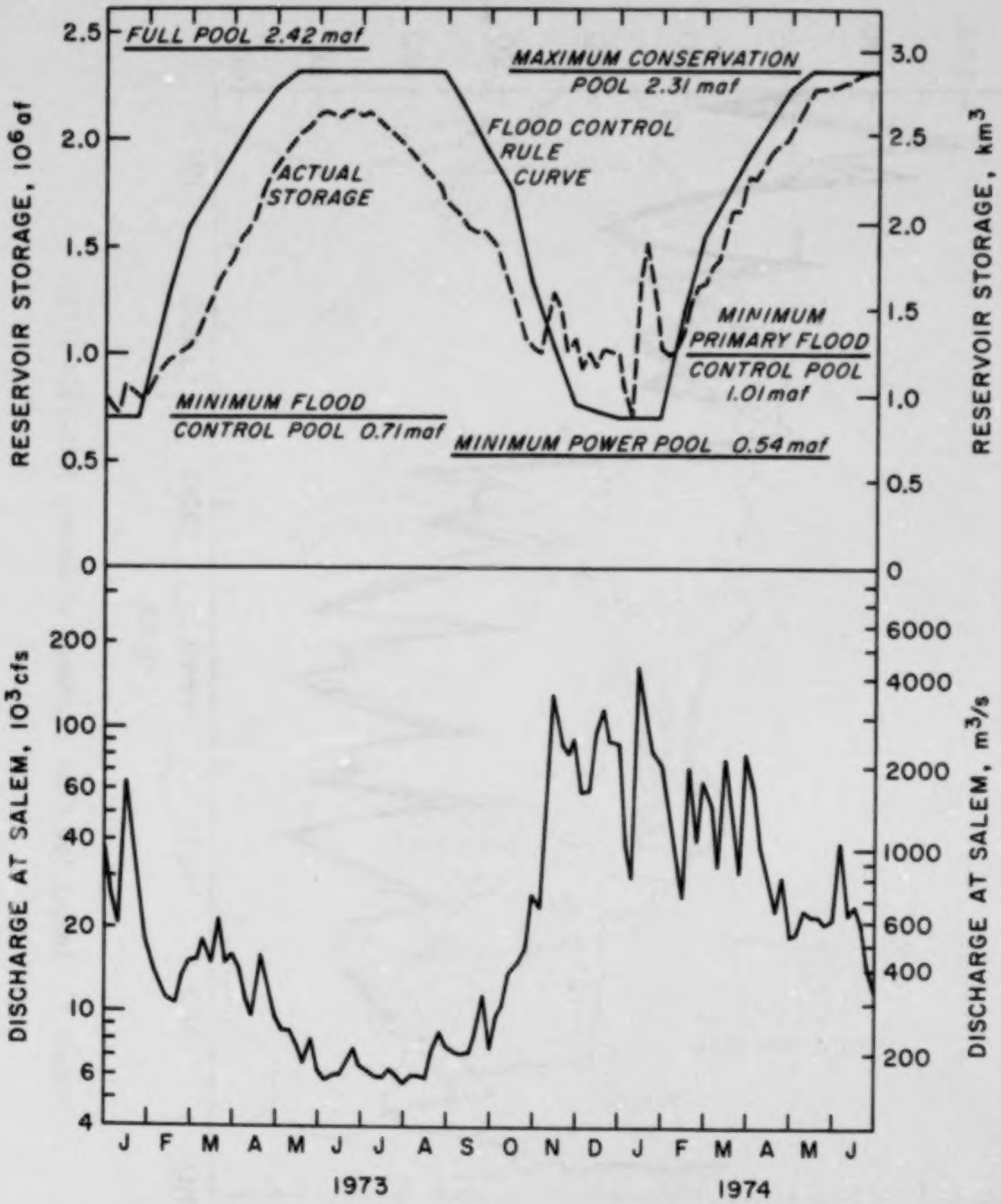


Figure 6. Willamette (a) reservoir rule curve, storage, and (b) discharge at Salem, 1973-1974 (8, 11, 12).

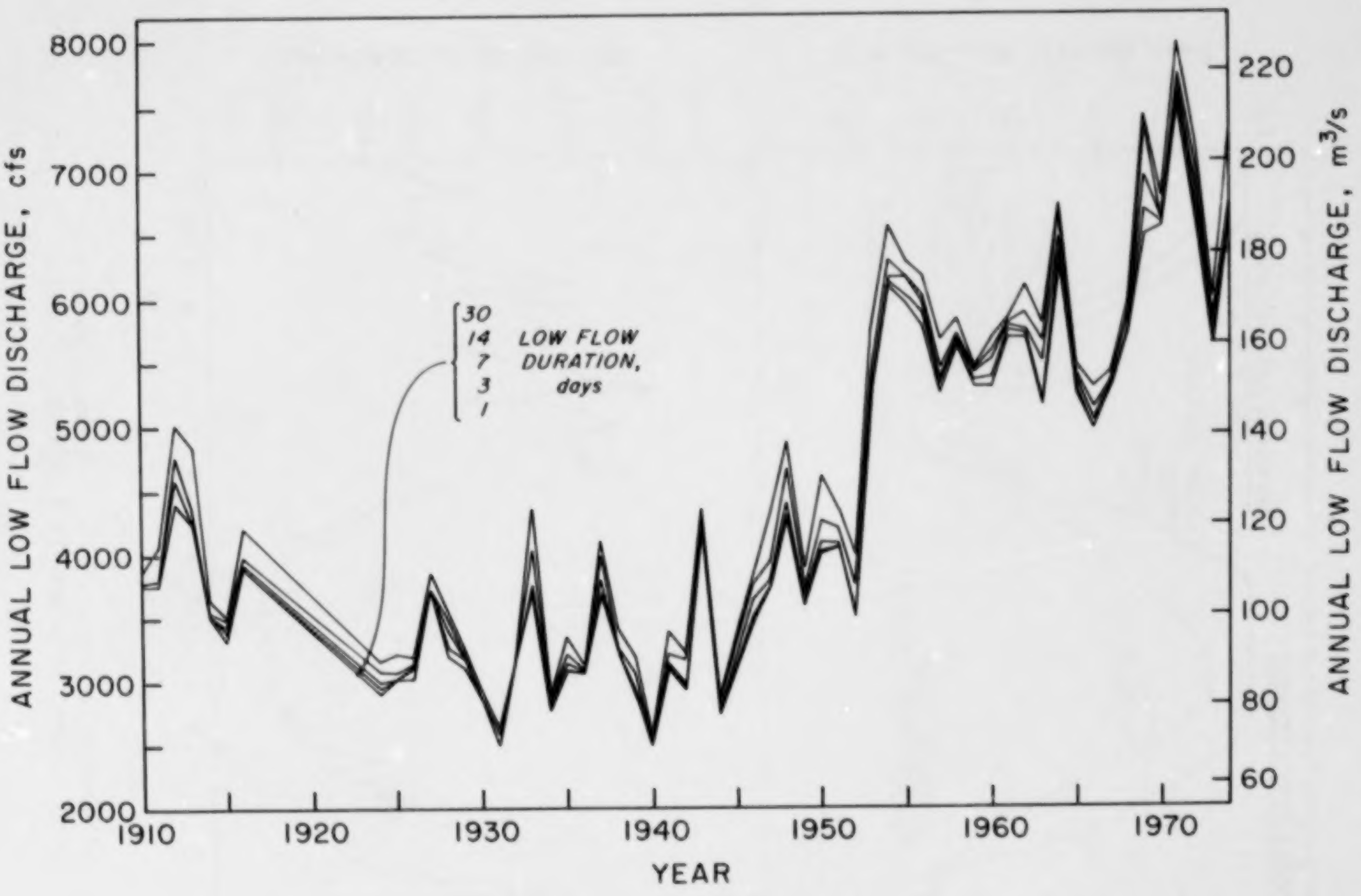


Figure 7. Annual low flow discharge at Salem, 1910-1974 (12).

The temperature of the Basin is reflected in the temperature pattern of the river. The Willamette at Salem averages slightly above 5°C in the winter and approximately 21°C in late summer. The higher temperatures which coincide with lower, summertime streamflow intensify biological rates of oxygen utilization and decrease the water's capacity for dissolved oxygen saturation.

WATER RESOURCES DEVELOPMENT

Municipal and Industrial Water Supply

The water supply for the Basin's major urban areas is drawn from surface sources, but not generally the Willamette River. Of the urban areas listed in Table 2, only Corvallis is supplied from the main stem itself. Minimum main stem use for municipal water supply has come from traditional public hesitation to "drink someone else's sewage." The Willamette presently requires no more than conventional potable water treatment. Valley citizens acknowledge that the river is clean, but subtle prejudice still remains.

Pulp and paper manufacturing provides the Willamette Basin with a relatively stable basic export. Without such an industry, the Basin would experience the hazardous seasonal and financial fluctuations common to raw material economies. This industry requires large quantities of process water, but little is actually consumed. Present pulp and paper water needs require less than 3 percent of the river's minimum annual monthly low flow (10).

Irrigation

Irrigated land has more than doubled in the Willamette Basin in the past 20 years as shown in Figure 8(a). Sixty percent of the irrigation water used is derived from surface sources. More than 10 percent of the lands irrigated from streams receive supplemental supply from reservoir storage. Ninety-nine percent of such storage has additional benefits, principally flood control.

The value of crop and livestock production associated with irrigation in 1964 was $61 million. An economic multiplier encompassing indirect worth of this production is estimated to be 2. Approximately 8600 agricultural workers were employed in irrigated production with an additional 15 000 workers supported in allied industry and services (15, 16, 17).

Navigation

Since territorial days, the Willamette has provided Oregon with a navigation route to its agricultural heartland. Steamboats paddled as far upriver as Eugene. Logs were rafted down tributaries. Opened in 1873, the Willamette Falls Locks (normal total lift - 12.5 m) connect the river reaches. A 2.5-m channel is maintained below the Falls and a 1-m route extends above the Falls to Eugene. Federal expenses for navigation improvement through 1974 were approximately $20 million for locks and $17 million for channel maintenance (18).

The advent of railways, freeways, and pipelines has reduced dependence on river transportation. Over the past 35 years, river traffic has remained fairly constant. Annual haulage is approximately 4 million metric tons, as

TABLE 2. POPULATION CENTERS IN THE WILLAMETTE BASIN (13)

Population center	1976 Population
Portland	382 000
Eugene	96 660
Salem	80 000
Corvallis	40 180
Springfield	35 580
Beaverton	23 300
Albany	22 800
Milwaukie	17 300
Hillsboro	20 100
Lake Oswego	19 700
Estimated basin population	1 588 000

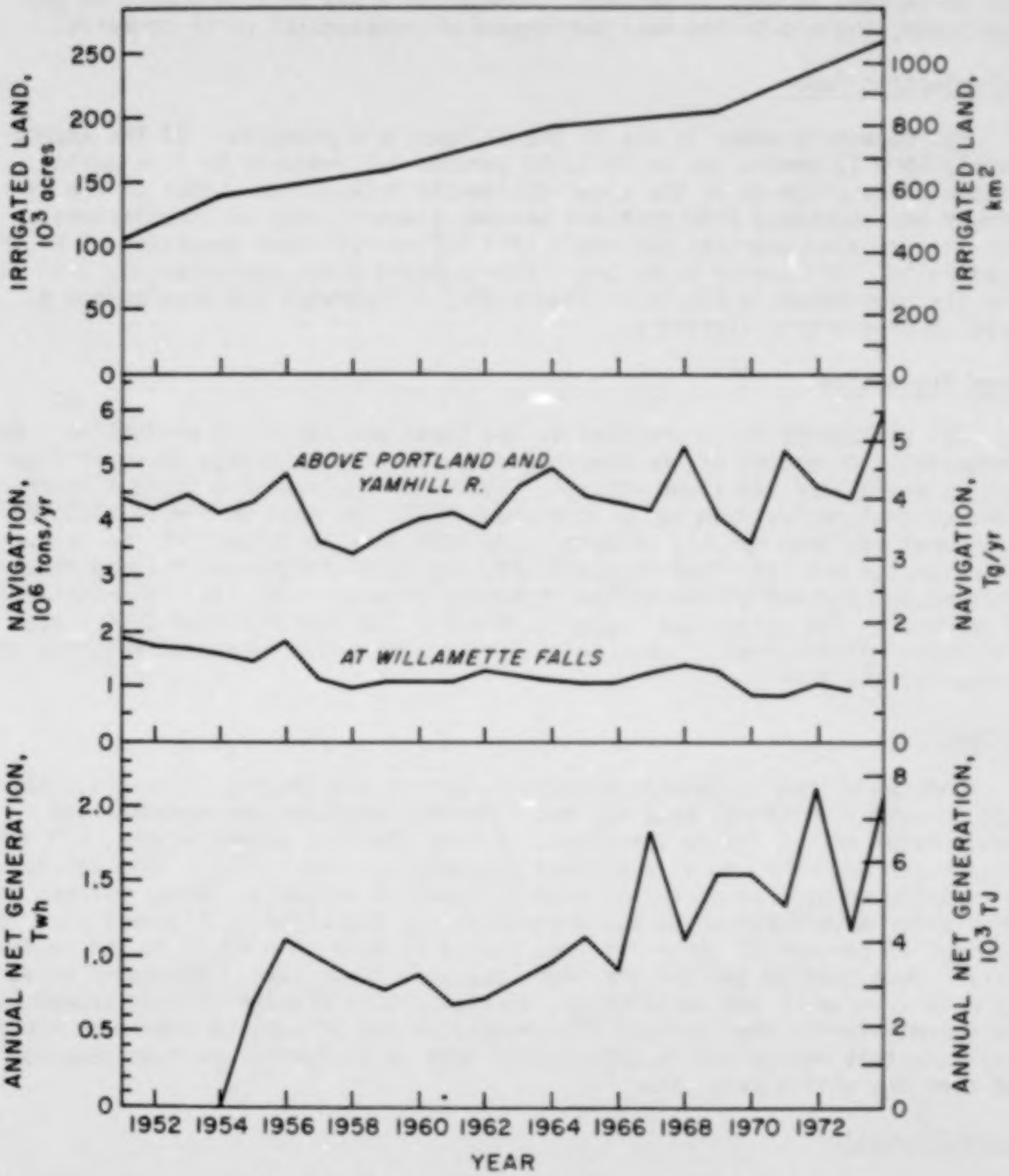


Figure 8. Willamette (a) irrigation, (b) navigation, and (c) electrical generation, 1951-1974 (15, 16, 18, 19).

shown in Figure 8(b). The rafted log portion of this total has fallen from over 50 percent to only 10 percent. Except for a few bulk shipments to and from Salem, the mid-Valley does not depend on substantial river commerce.

Hydroelectric Power

Hydroelectric power is one of the Willamette's products. Of the approximately 8500 TJ generation in 1973, 50 percent was produced by five multipurpose Corps projects on the upper Willamette tributaries. Most of the remainder was developed from Portland General Electric dams on the Clackamas. This utility also operates one small (415 TJ) run-of-river generator at Willamette Falls. The Eugene Water and Electric Board draws approximately 1000 TJ from the high McKenzie (3, 20). Figure 8(c) illustrates the development of Corps' hydroelectric facilities.

Flood Protection

All Willamette Basin projects by the Corps provide flood mitigation. Approximately 70 percent of the combined Corps reservoir storage shown in Figure 9(a) is designated for flood control. Reservoir construction costs alloted to flood control ranges from 32 to 70 percent (21). As seen in Figure 9(b), this investment has been quickly returned. By 1974 when 50 percent of the Basin's flood storage was less than 14 years old, the total reduction in flood damages exceeded 125 percent of the entire reservoir expenses (18, 22). Approximately 70 percent of the return was incurred with the 100-year flood of 1964. Had this flood not occurred, flood control investment would have been returned at an approximate 6 percent rate.

Recreation

Throughout the Willamette watershed, hiking and camping sites are proximate to water. Fishing, boating, and swimming locations are abundant and scenic motor routes follow waterways. During the peak summer months, 175 000 persons per day make use of developed recreational sites (23). This demand is expected to grow at an annual rate of nearly 4 percent. Twenty percent of the visitor days occur at Corps' reservoirs, as indicated in Figure 9(c). Typically, 75 percent of these visitors travel no more than 80 km to the reservoirs. More than 50 percent are from less than 40 km (24). Reservoir sites are more favored by day vacationers, whereas remote fishing streams appeal to the overnighters. What perhaps differentiates the Willamette from many other basins is that recreation is enjoyed not only in protected upstream reaches, but over the entire main stem.

Waste Disposal

The Willamette is extensively employed to assimilate municipal and industrial wastewater discharges. Oregon's Department of Environmental Quality (DEQ) monitors aquatic waste discharges, relates such discharge to water quality, establishes discharge limits to protect and enhance that quality, and enforces those determinations.

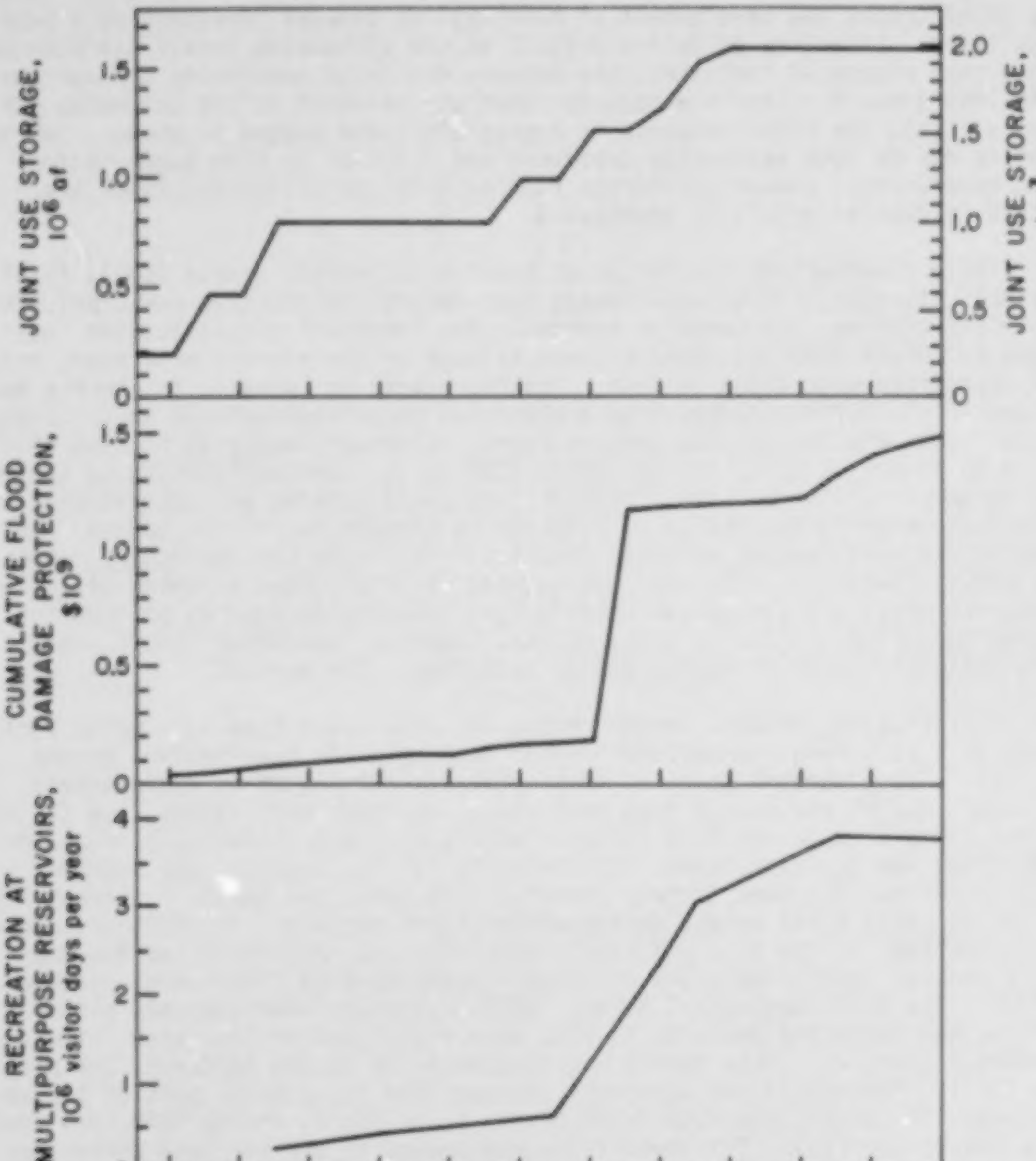


Figure 9. Willamette (a) joint use storage, (b) flood damage protection, and (c) reservoir recreation, 1951-1974 (18, 23).

Major wastewater dischargers can be seen in Table 3 and Figure 10. Figure 11(a) traces the development of municipal wastewater treatment on a population basis. Effective pollution control on the Willamette itself has been more rapid than Figure 10 indicates; the primary discharge continuing through the late 1960's was Portland's wastewater that was released to the Columbia. In Figure 11(b), the river response in August dissolved oxygen is shown. Improvement is due to both wastewater treatment and dilution by flow augmentation from reservoirs. Summer discharges flowing into the Willamette River are listed in greater detail in Appendix A.

Table 4 summarizes discharges of biochemical oxygen demand (BOD), total Kjeldahl nitrogen, and orthophosphate into the Willamette from municipal, industrial, unknown, and nonpoint sources. The "unknown" classification indicates pollutant loadings found by mass balance in the river's main stem, but not identified with known inflows. The "nonpoint" designation is loosely employed; pollutant discharges from tributaries minus residuals of up-tributary point inputs are lumped into this category. Although nearly 30 percent of the Basin is in agriculture, irrigation is limited to light application by sprinkler systems. Scattered animal feedlots and poultry farms are not believed to contribute significant pollutant loadings to streams during the summer. Extensive clearcut logging activity (particularly in the Cascade Range) increases the annual loading of sediments and organic material, some of which may affect summer chemical and biological conditions. Other major sources of nonpoint source pollution, including construction, highways, and urban runoff, contribute pollutant loads primarily during rainy high flow periods.

Historically, benthal oxygen demand has been identified as a major contributor to a recurring, summertime "oxygen dip" noted in the Portland Harbor (1, 28). These benthal deposits were primarily attributed to two sources: (1) overflows of raw sewage from Portland's combined sewer system, and (2) suspended matter, wood, and pulp fibers discharged from upstream pulp and paper industries and municipalities. By the early 1970's, however, the combined sewer overflows had been largely rerouted to a municipal sewage treatment plant on the Columbia River except during winter storm periods. In addition, secondary treatment by the pulp and paper industries and municipalities has drastically reduced their discharges of oxygen-demanding wood fibers and suspended solids. The U. S. Geological Survey (USGS) estimated that the only significant oxygen demanding deposits in 1973 were restricted to the reach below river kilometer (Rkm) 21. This demand was thought to be 18 000 kg/day in the reach Rkm 11-21. The demand was apparently responsible for a major part of the approximate 10 percent decrease in DO levels below Rkm 21 during 1973-1974 low-flow conditions (29). This benthic oxygen demand in the Portland Harbor was proportioned as follows:

(1) 25 to 33 percent due to natural benthal sediments,
(2) 25 to 33 percent due to algal respiration, and
(3) 25 to 50 percent due to an unknown combination of raw sewage overflows, ship discharges, navigation dredging, riverbed gravel mining, and resuspension of benthal materials by tidal currents and prop wash (30).

TABLE 3. PRINCIPAL WILLAMETTE BASIN MUNICIPAL AND INDUSTRIAL WASTEWATER TREATMENT FACILITIES IN 1973 (10)

Municipal facilities	Industrial facilities
1. Salem	A. Wah Chang, Albany
2. Eugene	B. Rhodia, Portland
3. Corvallis	C. Pennwalt, Portland
4. Springfield	D. Evans Products, Corvallis
5. Albany	E. Boise-Cascade, Salem
6. Portland - Tryon Creek	F. Publishers Paper, Oregon City
7. Fanno Creek	G. Publishers Paper, Newberg
8. Oregon City	H. Crown Zellerbach, Lebanon
9. Beaverton	I. Weyerhaeuser, Springfield
10. McMinnville	J. Western Kraft, Albany
11. Oak Lodge	K. Crown Zellerbach, West Linn
12. Milwaukie	L. American Can, Halsey
13. Metzger	M. Oregon Metallurgical, Albany
14. Aloha	N. General Foods, Woodburn
15. Sunset	O. Tektronix, Beaverton

TABLE 4. ESTIMATED LOADING OF P, N, AND BOD TO THE WILLAMETTE RIVER, AUGUST 1973 (7, 9, 10)

Source	Orthophosphate as P		Kjeldahl N as N		BOD_5	
	kg/d	percent	kg/d	percent	kg/d	percent
Municipal effluents	1 300	66	5 700	25	12 200	25
Industrial effluents	300	14	10 300	45	19 900	41
Unknown*			5 900	26		
Nonpoint Source	400	20	900	4	16 900	34
TOTAL	2 000	100	22 800	100	49 000	100

*See Section VI for discussion

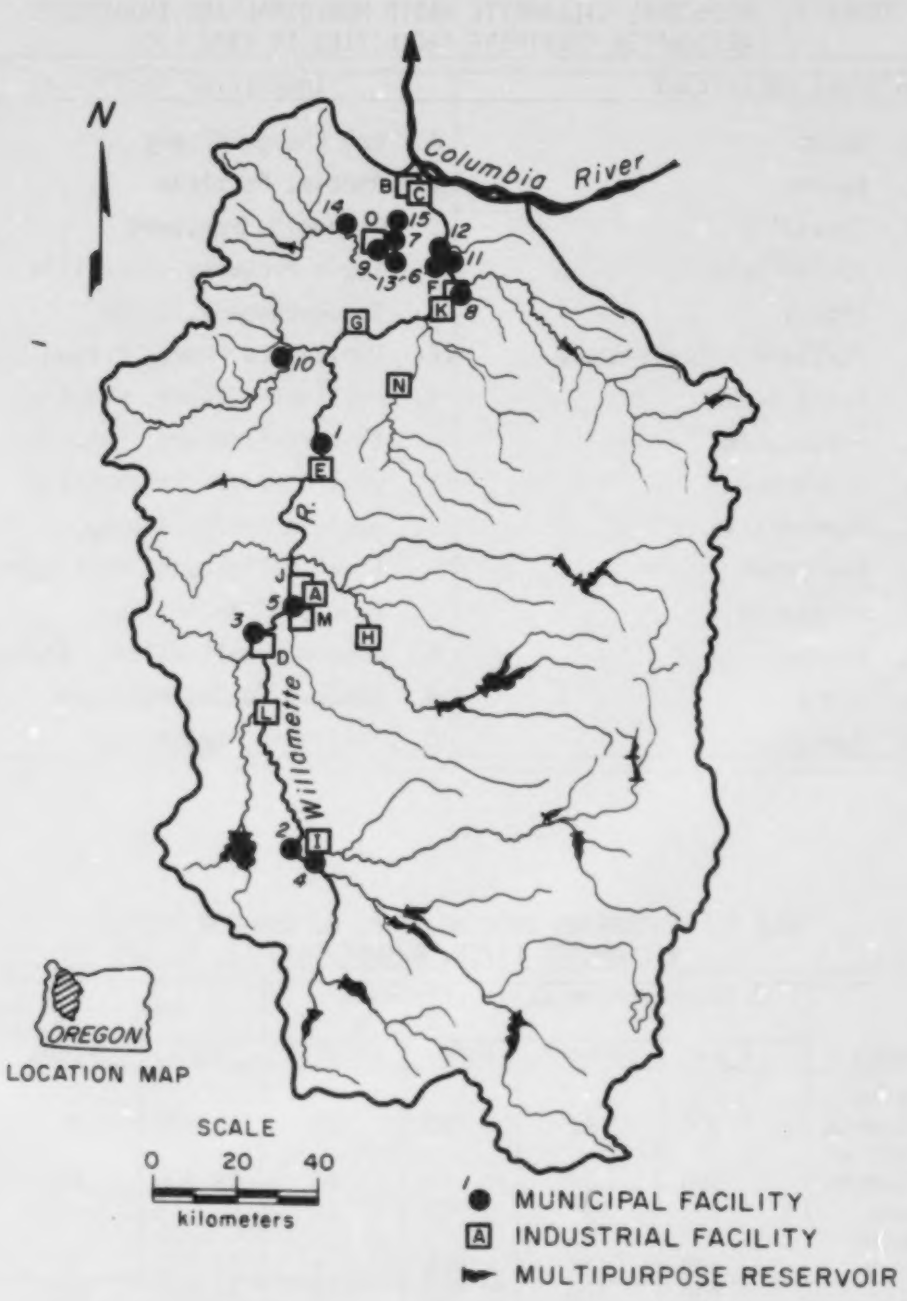

N
Columbia River
B
C
14
0
15
7
12
9
13
6
11
F
K
8
G
10
N
1
E
R.
J
A
5
M
3
D
H
L
Willamette
2
I
4
OREGON
LOCATION MAP
SCALE
0 20 40
kilometers
1
MUNICIPAL FACILITY
A
INDUSTRIAL FACILITY
MULTIPURPOSE RESERVOIR

Figure 10. Principal Willamette Basin municipal and industrial wastewater treatment facilities (see Table 3 for key).

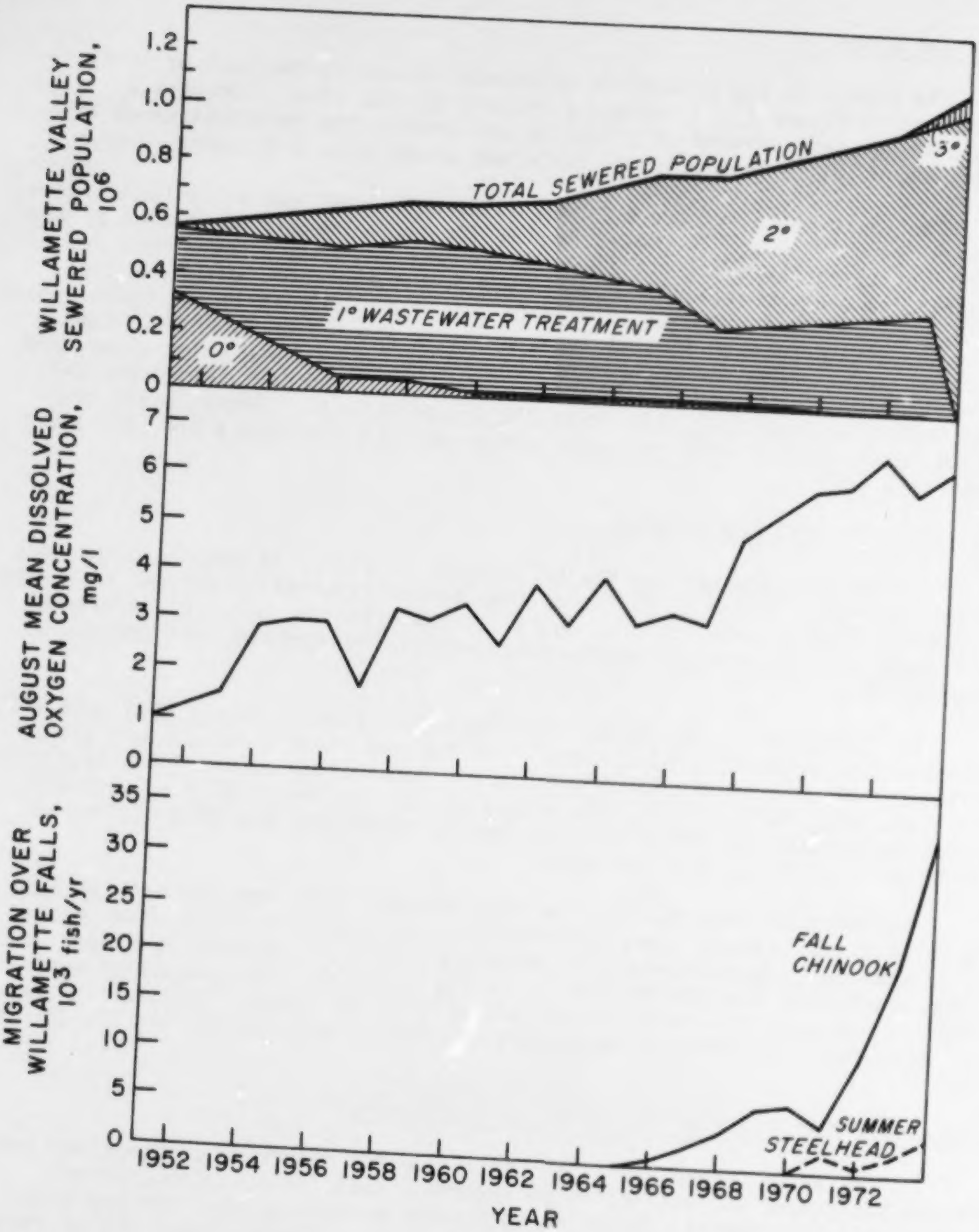


Figure 11. Willamette (a) sewered population, (b) dissolved oxygen, and (c) fish migration, 1951-1974 (3, 25, 26, 27).

Fish and Wildlife

The return to the Willamette of chinook salmon in the fall of 1973, illustrated in Figure 11(c), marked a victory for the river. Oregonians lined the banks to see a reward of pollution abatement. The preservation of fisheries and wildlife in a multiuse river was shown to be achievable.

The Basin contains four National Wilderness Areas and seven Federal Research Natural Areas. The Basin is home for approximately 70 species of mammals, including the Roosevelt elk, gray and red fox, black bear, mule and blacktailed deer, mountain lion, mountain beaver, raccoon, ermine, weasel, mink, and river otter. Over 30 reptile and amphibian species are found. More than 40 species of fish inhabit the Willamette and its tributaries. Coho, sockeye, and chinook salmon; cutthroat, rainbow, brown, and brook trout; and largemouth bass are fished. Sturgeon, carp, dace, and sculpin are present. Ornothologists have identified over 150 breeding birds. Geese, great blue heron, teal, kingfishers, mallards, merganser, and sandpipers are seen along waterways (31).

Pollution Control Expenditures

The return of water quality illustrated in Figure 11 was purchased, not freely gained. Figure 12 indicates the capital investments for (a) wastewater treatment plants, interceptors, outfalls, and lift stations, (b) industrial pollutant removal, and (c) multipurpose reservoirs used for instream pollutant dilution.

Capital expenses for Valley treatment plants as of August 1973 were $67.2 million (all costs in 1973 dollars). At the end of 1974 the sum was $143.3 million. Of this total, $58.6 million was spent after August 1973, $7.7 million was invested in plants discharging out of the Basin, $3.9 million was spent for plants not discharging to streams in August, and $5.8 million was invested in plants since abandoned.

Construction records indicate that through 1973, over $87 million had been invested in Basin sewer interceptors, wastewater outfalls, and sewage lift stations. Approximately 60 percent of this sum was used to remove Portland discharges from the Willamette to the Columbia. For industrial wastewater cleanup in this same period, $72 million was spent. Construction value of the Corps' multipurpose reservoirs exceeded $1 billion (3, 18, 22, 25, 26, 27).

Reservoir Authorization for Water Quality Control

A review of Congressional authorization for reservoir construction provides background for estimation of reservoir cost for pollution control. Water pollution control is not an authorized primary purpose for any Corps' Willamette reservoir. The Willamette River Basin Flood Control Act of 1938, the original authorization for Willamette reservoir construction, followed the heralded Columbia and TVA patterns for development: regional economic growth stemming from flood control, power, navigation, and irrigation. Congress laid out a plan of reservoir construction on Willamette tributaries for those ends.

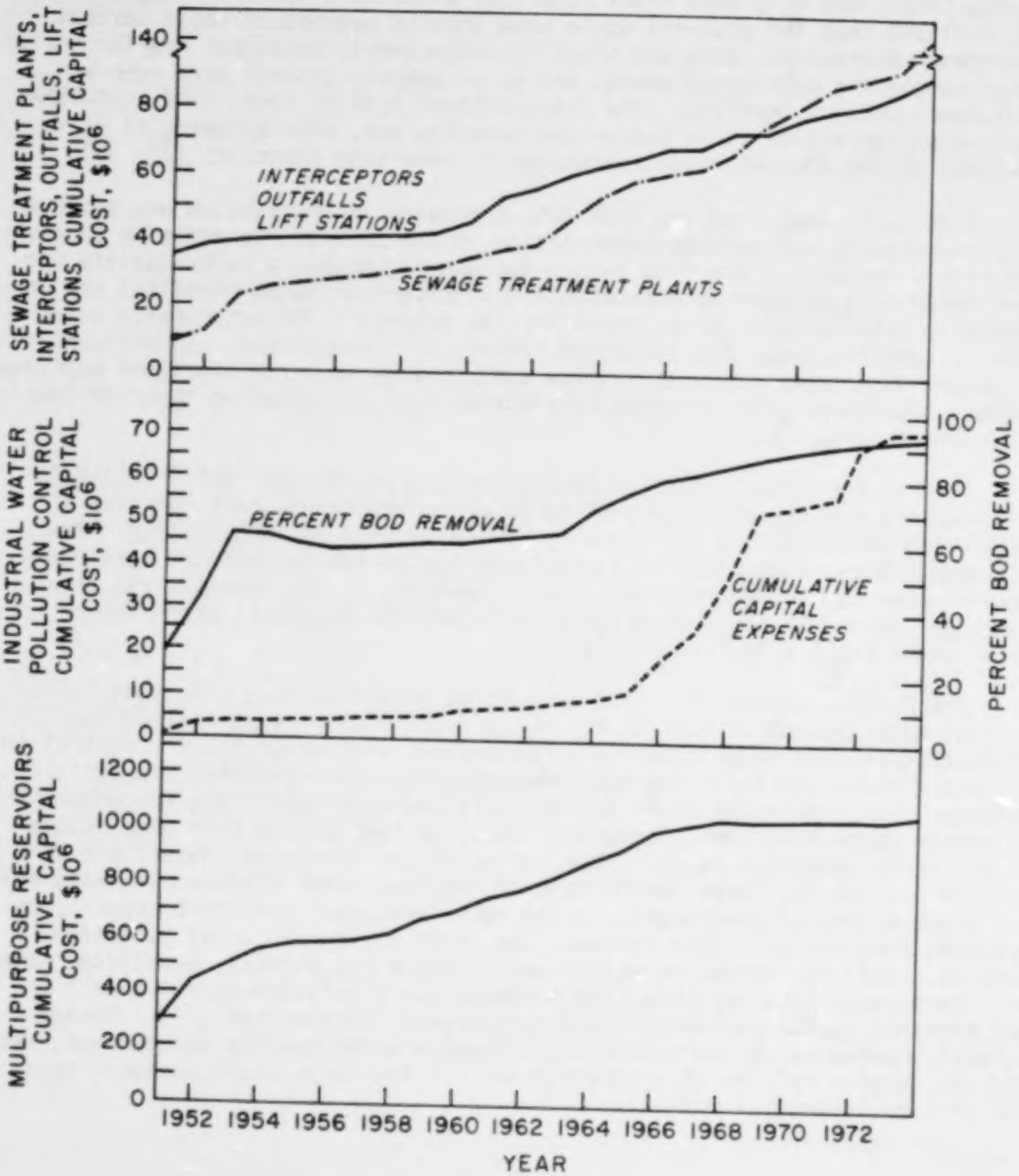


Figure 12. Willamette (a) municipal and (b) industrial wastewater treatment and (c) reservoir costs (18, 22, 25, 26, 27).

By the 1950's and 60's when final reservoir plans were drawn and approved, it was realized that the projects would have impacts outside of those several purposes. Recreation, fish and wildlife enhancement, municipal and industrial water supply for downstream users, and water quality control were seen as additional project benefits. The Flood Control Acts of 1944, 1946, and 1954 designated recreation as an authorized specific use, thus allowing it to be included in the comprehensive evaluation of reservoir economics (32, 33).

Within the limits of the 1938 Act, a broader interpretation was given to project purposes of low flow augmentation in the 1950's. In addition to navigation and irrigation benefits during the summer season, a water quality control benefit (then seen as approximately 3 percent of total benefits) was included in benefit-cost calculations for the project. The anticipated water quality benefits reflected pollution control cost reductions. Significantly, pollutant dischargers did not realize such savings in waste treatment expenses. Rather, the dischargers incurred substantial cost in upgrading their effluents to secondary quality.

The Federal Water Pollution Control Act Amendments of 1961 (PL 87-88) provided for water quality control to be a recommended project function for reservoirs being planned and those in initial stages of construction. The Willamette Basin Comprehensive Study investigated and recommended such addition of purpose for Federal reservoirs. However, by the time of this determination, the Corps had successfully justified its reservoir plans independently of water quality improvement (21).

The Corps' conservative cost accounting proved to have foresight. The Federal Water Pollution Control Act of 1972 (PL 92-500) again called for streamflow regulation policies to be determined with water quality control in project economic design. The Act, however, also specified that storage and releases from reservoirs could not be justified as a substitute for adequate at-source waste treatment, "adequate" being defined as the best practicable or available technical level. Thus, water pollution control benefits could only be claimed for Corps' projects that improved water already receiving only the highest treated discharges. Since such "adequate" treatment capacity approaches complete pollutant removal, the Corps could only count pollution control credit for improving water quality above its natural, unpolluted level. In effect, water quality from flow augmentation ("solution by dilution") are not presently authorized benefits for reservoir construction (34). Though Federal reservoirs do contribute to Willamette water quality maintenance, the DEQ can neither rely on this strategy nor can the Corps claim economic benefits for this environmental service.

SUMMARY

The Willamette Basin's physiographic setting gives rise to its varied water resources. The State Water Policy Review Board summarizes:

1. The total surface water yield in the basin is sufficient to meet all foreseeable needs,
2. The temporal distribution of runoff results in water shortages in some areas,

3. Low flow augmentation can be obtained through storage of winter flows, and
4. Augmented flow is required to protect several seasonal water resource benefits (35).

Water resource employment is varied, but to a large extent complementary. Reservoirs are maintained at high levels for much of the recreational season. Reservoir releases in preparation for the winter flood season coincide with downstream needs for water supply and water quality protection. To the present, consumptive use of the Willamette, principally for irrigation, has not greatly competed with instream water requirements.

Mankind's employment of the Willamette River has increased over the years. To both make use of the river resources and maintain water quality, substantial investment has been made for water pollution control. A portion of this investment has gone for wastewater collection, treatment, and diversion. Another portion of these costs has purchased augmented flow, an unauthorized benefit from multipurpose reservoirs.

SECTION V

POLICIES

PERSPECTIVES FOR RESOURCE MANAGEMENT

Governmental policies can be described as high-level overall plans that embrace general goals and acceptable procedures. From those policies, resource management issues emerge which involve environment, economics, and energetics. Resource management reflects environmental policies, plans, and procedures for protecting natural resources. Resource management is a major part of economic policies that seek to increase the material enjoyment of life. Utilization of natural resources often reflects energy policies that direct work allocation. Any of the three policies can, in fact, be conceptualized as incorporating the remaining two. Although man could unify his resource management policies under one perspective, this is generally not done. Rather, issues are examined from several viewpoints, each with somewhat independent policies. The selection of a particular solution seems to depend on the compatibility to the most or highest-order policies. This determination is typically social, not technical.

When policies are well defined, ranked, and accepted, issues of resource utilization can be easily resolved. However, if the policy perspectives are not well defined or generally accepted, resource decisions become difficult.

This section explores three policies pertinent to Willamette pollution control. Environmental, economic, and energy policies are introduced so that analytical results presented later in this report may be compared to public goals. If policy and prediction seem to substantially differ, then recommendation to make policies more realistic can be made.

ENVIRONMENTAL PERSPECTIVE

The Water Quality Management Plan

The Oregon Department of Environmental Quality's (DEQ) Water Quality Management Plan reflects the State's commitment to pollution control. The plan, adopted December, 1976 in compliance with Federal regulation PL 92-500 furthers Oregon's tradition of being a frontrunner in water pollution abatement.

> "Whereas the pollution of the waters of this State constitutes a menance to public health and welfare, creates public nuisances, is harmful to wildlife, fish and aquatic life and impairs domestic, agricultural, industrial, recreational and

> other legitimate beneficial uses of the water, whereas the problem of water pollution in this State is closely related to the problem of water pollution in adjoining states; it is hereby declared to be the public policy of this State:
>
> (1) To conserve the waters of the State;
>
> (2) To protect, maintain, and improve the quality thereof for public water supplies, for the propagation of wildlife, fish and aquatic life and for domestic, agricultural, industrial, municipal, recreational and other legitimate beneficial uses;
>
> (3) To provide that no waste shall be discharged into any waters of this State without first receiving the necessary treatment or other corrective action to protect the legitimate beneficial uses of such waters;
>
> (4) To provide for the prevention, abatement and control of new or existing water pollution; and
>
> (5) To cooperate with other agencies of the State, agencies of other states, and Federal Government in carrying out these objectives." (36)

The Water Quality Management Plan seeks to continue a determined and cooperative pollution reduction policy by proven means of waste treatment. Implementation of the plan calls for more advanced wastewater treatment to reduce carbonaceous BOD, suspended solids, and coliforms. The plan recognizes problems of nonpoint source pollution and riverbed benthic materials as future, not immediate, targets for control. To limit industrial wastewater effluents the plan extends Oregon's pragmatic approach of seeking reasonable industrial cooperation in lieu of governmental litigation. The Water Quality Management Plan is a substantial conventional sanitary engineering endeavor.

Goals of the Water Quality Management Plan are transformed into tactical regulations by the DEQ. Relevant to the environmental model developed in the next section are the DEQ's standards. In the tidal reach below Willamette Falls the minimum permissible dissolved oxygen (DO) is 5 mg/l. Above the Falls to Newberg the level is 6 mg/l. From Newberg to Salem the standard is set at 7 mg/l above Salem, 8 mg/l.

Environmental Policy

The generalized State environmental policy is illustrated by the Water Quality Management Plan. State goals call for (1) the prohibition of further environmental degradation within the State, and (2) the improvement of natural resource quality where practicable. Acceptable procedures for these ends include (3) pragmatic cooperation between Federal, State, local, and industrial officials, and (4) the maintenance of regulations and enforcement capacity directed toward environmental quality.

ECONOMIC PERSPECTIVE

Oregon's economic policies center on the general goal of improving per capita income and reducing unemployment (37). Economic policies are perhaps easier to identify in action than in legislation, as activity speaks for itself. Several indices of economic behavior are discussed below.

Indices of Resource Utilization

Ten percent of American softwood timber stands in the Willamette Basin. Of the Basin timber harvest, 90 percent is sent to national and world markets (11). The pulp, paper, and particle board industry steadily converts sawmill wastes (once incinerated) into marketable goods. Statewide, the value of the forest products industry's payroll exceeds $1 billion. Forty-two percent of the State's entire population receives income derived directly or indirectly from the forest industry (38). The Basin is a foremost producer of grass seed, hops, and mint. Nearly half of the State's $1 billion annual farm and ranch gross sales comes from the Valley (39). One out of five workers in the Basin is employed in renewable resource harvest and processing (11).

Oregon sportsmen devote more than 2 million person-days yearly to hunting and fishing. Sportsmen pay license fees (approaching $10 million annually) and help sustain a year-around tourist industry (40). In short, the economy of the Willamette Basin is significantly derived from the harvest of renewable natural resources.

The aesthetics of the natural environment and the prosperity derived from resource harvests have drawn to the Valley small non-resource based firms. A large part of Valley industry produces commodities of high value and little bulk, e.g. electronic equipment or refined rare metals. Such industry is actively sought by the State. Should living conditions, local taxes, or State regulation become unacceptable, these industries possibly would leave the area.

Indices of Income

Mean personal income in the Willamette Basin is greater than that of the rest of the State ($5520 versus $4770 in 1974), the difference in large part due to the Valley's urban employment. In the past 25 years, the Basin's median family income has improved relative to that of the State. In this period, the majority of Willamette Valley counties dropped below the State mean percentage of families living in poverty. Income is more evenly distributed in the Valley than in the State as a whole. By any of the four measures (mean income, median income, poverty percentage, and income distribution), the Valley has a reasonably healthy income (41).

Indices of Population

Willamette Valley counties have experienced a 1.74 annual percent growth in population over the past 15 years. Although population stabilization is now generally assumed to be a necessary condition for preserving the Valley's quality of life, in the next decade the rate is not anticipated to greatly change (21, 42). Somewhat less than half the population growth in Oregon is attributable to immigration (43).

Economic Policy

The masthead of the State Economic Development Commission once heralded "Oregon, the Growth State". Its newsletter was "Grow with Oregon". However, environmental issues of the 60's have brought reevaluation. "Grow with Oregon" was relabeled "Oregon Quality" in 1970. Perhaps the subsequent title "Oregon Progress" reflects a slight rebound, a middle way. An economic policy for Oregon has been established:

> "(1) There exists in the State a great and growing need for balanced economic and community development to provide and maintain orderly economic growth and the preservation and enhancement of all facets of Oregon's environment;
>
> (2) Only properly planned and coordinated growth and development can maintain and improve the total environment by broadening the tax base. . .;
>
> (3) . . . Balanced development opportunities must be made available to rural areas to bring about the geographical distribution of business and industry necessary to a healthy economy and environment for all Oregonians;
>
> (4) Assistance and encouragement of balanced industrial, commercial and community development is an important function of the State. . .;
>
> (5) The availability of this assistance and encouragement is an important inducement to industrial and commercial enterprises to locate, remain and relocate in those portions of the State which will contribute most of the environment and economy of Oregon. . .; and
>
> (6) Development of new and expanded overseas markets is an area of great potential for furthering balanced economic growth. . . thereby contributing to economic diversification." (44)

Redundant in the policy is the State economic goal: to sustain economic growth. There is little willingness to forego the benefits of resource harvests, the healthy Basin income pattern, or the population growth complementary to traditional economic development. There is general willingness to invest dollars in pollution management to avert the penalties associated with a polluted region.

ENERGY PERSPECTIVE

Energy is required for protection of multipurpose environments, yet energy production often degrades that environment. Energy consumption is required to fuel an economy, but energy depletion may curtail much economic activity. This section outlines several aspects of Willamette Basin energy use, illustrating problems confronting energy policy of the 1970's.

Energy Consumption

Records of energy usage in the Willamette Valley incorporate electrical, natural gas, and petroleum product data. Whereas such accounting does not describe the area's total energy budget, the statistics do reveal significant and manageable aspects of the region's energy base. Unless indicated otherwise, the trends and generalities of the State are substantially the same for the Willamette Valley.

Energy consumption in Oregon regularly increased until the oil embargo of 1973 (Figure 13). Oregon's energy consumption growth rate has historically been more variable than that of the nation. Overall, Oregon has experienced a higher than national rate of energy growth (4.7 versus 3.3 percent average growth rate of total energy consumption and 2.8 versus 2.2 percent average annual per capita increase, 1962-1974) (45, 46).

Oregon's petroleum and natural gas requirements are met by imports. Thirty-three public and private utilities in 1974 supplied the State's electrical needs. These utilities are members of the Northwest Power Pool, a program of unified regional power production. Eighty-five percent of the Pool's production comes from dams. Of this, most comes from Bonneville Power Administration's Columbia reservoirs. Approximately 10 percent of the Willamette electrical consumption is hydraulically produced within the Basin (48).

Power is traded with the Pacific Southwest on an annual cycle. High Columbia summer flow generates electricity in excess of northwestern immediate demand. The surplus is transmitted via high voltage lines to California and Arizona. Electricity is returned during the winter when the southwest's cooling demands are reduced and the northwest's heating needs are greatest. Such transshipment is estimated to cost 25 percent as much as otherwise-required regional power plants for peak seasonal demands (47). The Willamette Valley, then, regularly consumes electricity generated throughout the western United States.

Energy Forecasts

Energy use forecasts vary. Private electrical power suppliers project nearly a complete continuance of the 6.3 percent growth rate from 1962-74. State officials, placing more credence in demand elasticity, expect 3.3 percent. In either case, no plateau in energy demand is foreseen. Increased electrical production will be derived from three thermal facilities (one coal and two nuclear) in eastern Oregon. The residential sector will demand most new electrical output.

Petroleum consumption is forecast to accelerate at a 4.5 percent rate. This exceeds the growth rate of the past decade. The clear assumption is that the oil will yet be available. Natural gas supply is predicted to decrease, jump, and decrease in the next 20 years. Industrial gas delivery will be cut back.

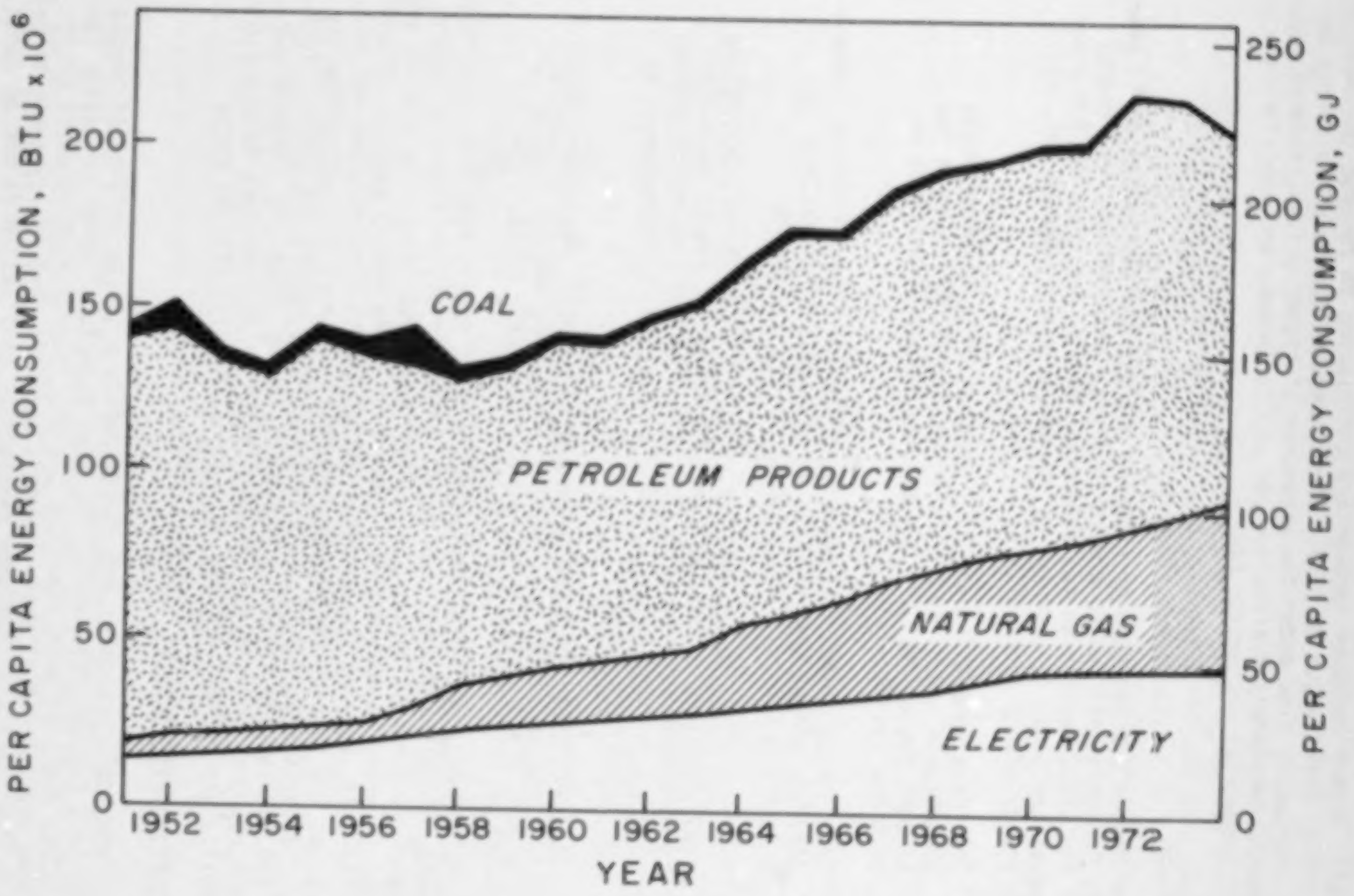


Figure 13. Oregon per capita energy consumption, 1951-1974 (45, 46).

Overall, higher consumer incomes are anticipated to reverse the temporary downward energy trend begun in 1973. The subsequent increases in energy demand will eventually slow under the pressures of higher prices, reduced population growth, decelerating effective per capita income, and diminishing expansion of industrial production (45).

Energy Policy

Given Oregon's dependence on imported energy, the decreasing world energy stocks and Oregon's anticipated growth in energy requirements, the energy policy of the State centers on two concepts: energy conservation for essential purposes and local development of renewable energy sources (45, 49). The State energy policy is briefly as follows.

> "(1) That development and use of a diverse array of permanently sustainable energy resources be encourage utilizing to the highest degree possible the private sector of our free enterprise system.
>
> (2) That through State government example and other effective communications, energy conservation and elimination of wasteful and uneconomical uses of energy and material be promoted.
>
> (3) That the basic human needs of every citizen, present and future, shall be given priority in the allocation of energy resources, commensurate with perpetuation of a free and productive economy with special attention to the preservation and enhancement of environmental quality.
>
> (4) That all State agencies, when making monetary decisions, take into consideration cost factors, including but not limited to energy resource depletion and environmental costs." (50)

Oregon's energy policy is essentially one of fossil fuel and electricity (high grade energy) management. Oregon's energy policy is directed toward both altered patterns of energy consumption and production. The overall goal is that of insuring an adequate long-term high-grade energy supply. Generalized policy calls for (1) the conservation of fossil fuel reserves for essential purposes and (2) the development of local, renewable energy producing capacity. Records and projections indicate (1) is not taking place. Technology of the foreseeable future is not apt to bring about (2). Unlike environmental and economic objectives, areas in which Oregon can turn to experience, energy policy may reflect desires not reconciled with all the facts.

AN ALTERNATIVE PERSPECTIVE

Environmental, economic, and energy policy might be unified if issues were seen in a broader framework. The many aspects of water pollution control strategy might be seen together, yielding coordinated resource management. Some overlapping of environmental, economic, and energy terms in policy statements does indicate that some perspective unification is coming about, but it is more semantic than actual.

A more methodological approach to comprehensive policy stems from the field of ecology. This perspective, popularized by H. T. Odum, calls for reduction of all activity to an energy structure (51). Such energy analysis requires both quantity and quality appraisal. Activity has quantity as calorie transfer and quality as its ability to bring about work. Energy used to regulate the flow of other energy is deemed to be of higher quality than the regulated energy. In so regulating, it can cause more work to be done than would occur otherwise. Odum's proposals for many of today's social and ecological problems call for strategic interaction of high and low quality energies. A calorie of electricity spent for household heating is to Odum ill-employed. The electrical calorie used to facilitate primary production of wood, say, might be better invested. Odum is concerned with energy's effect upon the world system, not just fuel for man's spending.

A realistic policy for the environment, economy, or fuel supply must conform to a viable total energy structure. Odum's approach to public policy formulation calls for the determination of the many fold energy pathways that sustain man's way of life. High quality energy used to pump more energy into the system is identified. If an inflow of energy is desired, the proper policy must be one in which the regulating energy flow is maintained.

In such light, the Willamette Valley might be viewed. Figure 14 represents an initial and partial conceptualization of the Valley's energy basis. Several inflows of energy enter the Valley. Two of them, solar and precipitation, are flow resources from essentially a constant sun, thus "renewable". The remaining two inputs, fuels and raw materials, are derived outside the Basin, in part from renewable sources, but mostly through depletion of national and international nonrenewable energy reserves. In-Basin renewable energy supply is shown as forest and crops, quantified by caloric value. Within the Basin, hydroelectric power is generated from precipitation runoff, estimated to be the potential energy of flow channelized in streams. Energy flows attributed to each of the above are indicated as caloric flux uncorrected for quality. Odum suggests fossil fuel equivalent units for all flows. Such correction for quality would yield 16×10^{12} Cal for sunlight, 5×10^{12} for primary production, 5×10^{12} and 10×10^{12} for crop and timber harvest, and 51×10^{12} for precipitation. The hydroelectric power produced in the region would be valued at 8×10^{12} fossil fuel equivalent Cal and the electricity imported, 56×10^{12}. All other values shown are expressed directly as fossil fuel equivalent energy units. Figure 14 may be modified in this manner to standard units. This modification is here left to the reader's discretion and to reader's agreement with Odum's method. Calculation of values shown is given in Appendix J.

An Odum-based evaluation of pollution control costs might extend to estimates of primary production lost with reservoir innundation or nutrient (high quality energy) return to agricultural land. In this investigation, such issues are not pursued. They are not unimportant topics, but rather questions presently outside the domain of government energy policy and thus beyond the objectives of this study.

The alternative policy perspective proposed is thus one schematized in an Odum manner, but not extended to his comprehensive "total" energy picture.

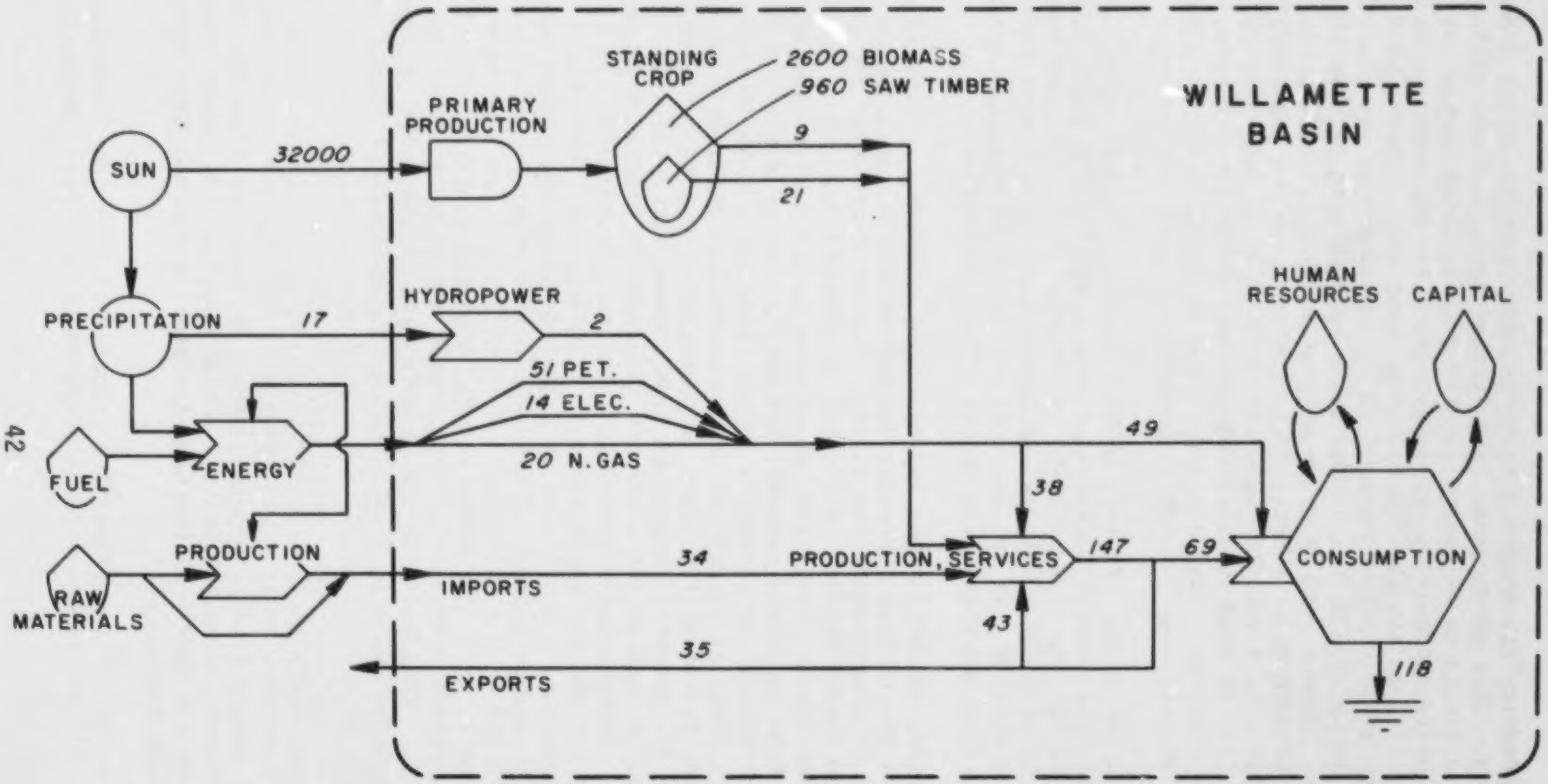

WILLAMETTE
BASIN
SUN
32000
PRIMARY PRODUCTION
STANDING CROP
2600 BIOMASS
960 SAW TIMBER
9
21
PRECIPITATION
17
HYDROPOWER
2
51 PET.
14 ELEC.
20 N. GAS
FUEL
ENERGY
RAW MATERIALS
PRODUCTION
IMPORTS
34
EXPORTS
35
49
38
PRODUCTION, SERVICES
43
147
69
HUMAN RESOURCES
CAPITAL
CONSUMPTION
118

Figure 14. Willamette Basin energy flows, 1973 in 10^{12} Cal per year.

The alternative policy perspective brings together aspects of pollution control, economic, and energy policies in a manner that would lead to coordination among those policies. Should a total energy perspective be pursued as planning evolves, the data of Figure 14 provide a framework for the economic portion of that effort.

Energy as imported power, materials, and capital is purchased with outputs of Valley economic production. Much imported energy, however, is not paid for with produce export. Because the market price for power has traditionally been much lower than the marginal value derived from that power, the Willamette Basin, like many affluent regions, has grown accustomed to development afforded by this net energy subsidy. The Valley's economic sectors of production and service transform this subsidy into goods and services enjoyed by Valley residents.

Though Figure 14 reflects only order-of-magnitude estimation, several conclusions can be drawn:

1. The Basin's economy is principally energetically maintained from imported nonrenewable sources.
2. The Basin benefits from an advantageous energy pricing situation. Far less than half the value derived from imported energy is exported in repayment.
3. The Valley cannot maintain current economic levels fueled by the Basin's wood or hydroelectric power.
4. The consistency of energy subsidies control the Basin's long-range economy, not industrial capacity within the Valley. A primary concern of Basin policy must be that of maintaining the external energy stock from which to draw. The consequences of Valley activity must be seen in a larger scale than that of local expenditure for power. The net national, and potentially international, effects must be anticipated. The policy reduces to a survival strategy within energy-imposed limits.

SUMMARY

Environmental, economic, and energy policies for Oregon are identified. Each has consequences significant to water pollution control. These policies provide perspectives from which the effects of resource management can be weighed. For Willamette water quality control, these policies will be used in Section X as illustrative criteria for management decisions.

The energy perspective of Odum has been used to identify patterns and limits to which workable environmental control must be reconciled. This alternative perspective will likewise be used later in this report to view strategies of water quality control.

SECTION VI

ENVIRONMENTAL MODELING

INTRODUCTION

A model is defined by Weinberg as: an expression of one thing we hope to understand in terms of another that we think we do understand (52). In modeling one seeks to integrate a rational set of concepts that satisfactorily describe a "real" system. Mathematics are commonly employed to provide an internally consistent, rigorous expression of the concepts. Modeling is a subjective enterprise. Models identify not necessarily the problem, but the modeler's notion of the problem. In this section a dissolved oxygen model of a river is discussed and its relationship to the larger issue of Willamette environmental quality is examined.

In environmental issues where a vast number of factors interplay, models frequently succumb to one of two errors. These errors either result from an unfortunate choice of what to model (error in model selection) or an unfortunate decision of how to model (error in model formulation). No matter how well expressed, a model of the wrong environmental attribute will fail to elucidate the behavior of interest. In addition, a model will be of little value if its analytic expression is inappropriate, no matter how carefully the environmental factors to model are chosen.

MODEL SELECTION

Dissolved oxygen (DO) models were among the first analytic expressions of water quality behavior and much is known about this type of model; however, DO models are often abused due to an over-confidence in their applicability. Having learned DO equations from textbooks, engineers too often immediately apply the calculations to any aquatic water quality problem. Other quality parameters may be given little consideration, not because of their lack of importance, but because models for these parameters are less familiar to the engineer. Conversely, DO modeling may be slighted by the engineer for the very reasons that it is older, not sufficiently complex, and less encompassing. The temptation is great to model "everything." Problems arise when an array of complex parameters, not necessarily appropriately modeled, masks the significance of the few parameters basic to understanding environmental conditions.

The Willamette has experienced both these modeling problems. Simple DO models have been applied for general or example results (53, 54, 55). Few model improvements were undertaken after the studies. The value of modeling was, thus, largely limited to immediate problems of interest to the investigator, usually an academician. Model extrapolation to the more general audience of planners was largely unsuccessful. The State Sanitary Authority in the 1950's anticipated Willamette water quality conditions primarily by insight, rather than by modeling.

Often present environmental analysis succumbs to the second problem of overencompassment. For example, models too complex for ready appraisal and modification, too reliant on generalities, too ignorant of local conditions, and too inclusive to unnecessary aspects have been applied to the Willamette (56, 57). Results were based on sparse data, inappropriate model structure, and coefficients determined without independent measure. Little confidence is merited for such model output.

Dissolved oxygen appears to be the most suitable parameter for quality modeling of the Willamette River. The reasons are specific to the river, not general to aquatic modeling. Parallel studies have considered other possible indices of pollution: metals, erosion-sedimentation, and nutrients (58, 59, 60). None of these parameters corresponds to the river's ability to sustain a diverse ecosystem better than DO. DO is an integrative parameter of the river environmental system. Natural regulation of river DO includes precipitation patterns, topography, groundcover, and the natural carbon and nitrogen cycles. Man-influenced controls include discharges of carbonaceous and nitrogenous wastes, land use as it affects runoff, and reservoir regulation. Thus, a model of Willamette DO can serve as an encompassing, broad-based expression of river environmental quality.

The rest of this section deals with the adequate expression of a Willamette DO model suited to the objectives of this study.

MODEL FORMULATION

A basic DO model is expressed as a multi-step mass balance. For river study, the channel is conceptually partitioned into reaches, each typified by hydraulic dimensions of width, depth, length, and discharge. Each reach receives inputs of oxygen, water, and oxygen demanding substances from the reach immediately upstream and/or from discharges along its banks. Within any reach, the DO concentration may be reduced by oxygen-demanding degradation of waste materials or increased by atmospheric or other reaeration mechanisms. A DO model can be visualized as a series of conceptual hydraulic reaches, each linked by interreach transport couplings, and each reach having potential oxygen sources and sinks. Boundary conditions are established and coefficients appropriate to internal model mechanisms are determined.

Oxygen sources and sinks meaningful for a Willamette model include biochemical oxygen demand (BOD), both carbonaceous and nitrogenous; immediate oxygen demand (primarily benthic exertion); and atmospheric reaeration. Figure 15 illustrates the basic dissolved oxygen model. Equations 1 through 5 define the expressions in general terms. The model is expressed in detail by the computer routines listed in Appendix B. The atmospheric reaeration term of Equation 1 is documented in Appendix C.

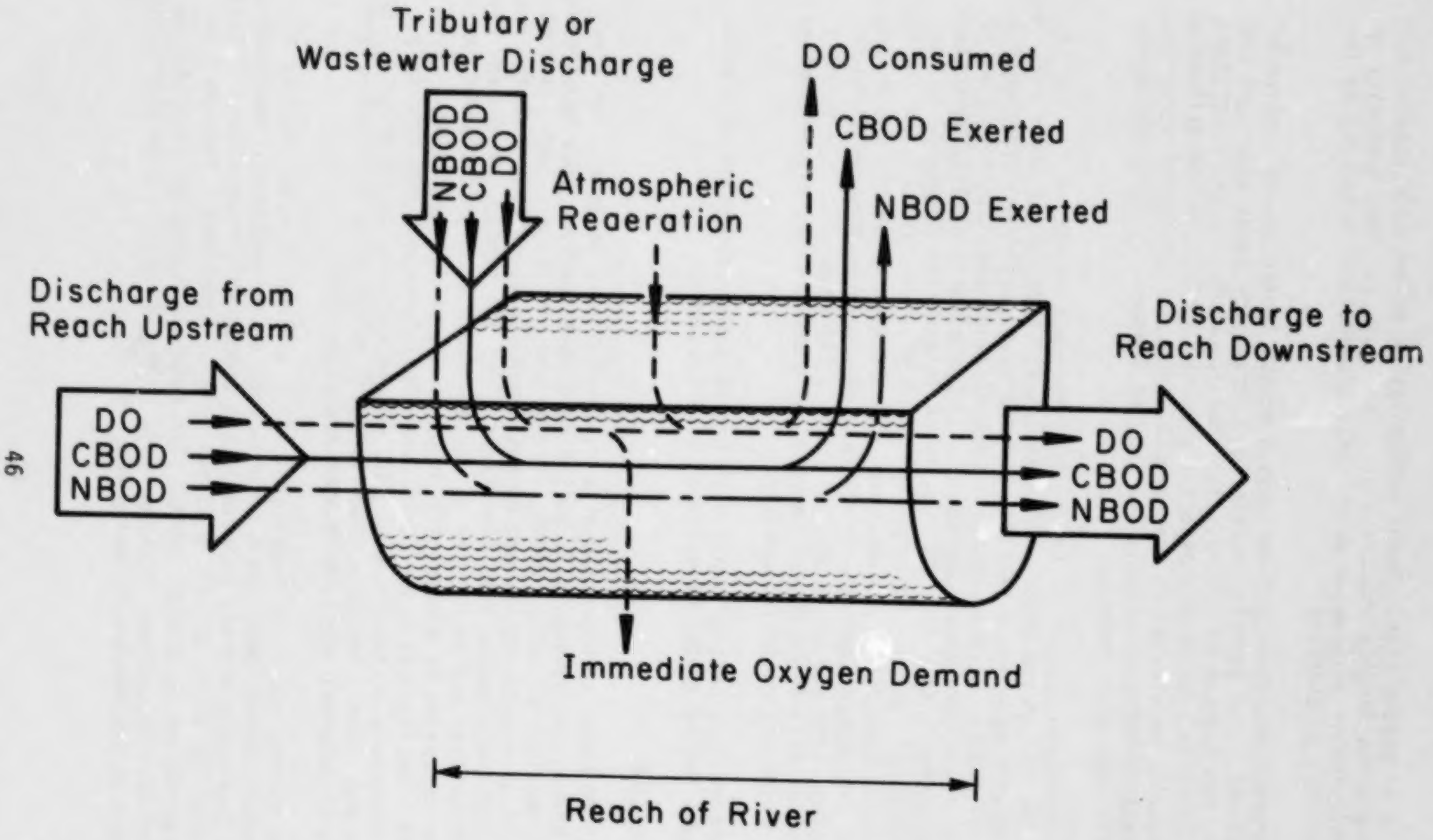

Tributary or
Wastewater Discharge
NBOD
CBOD
DO
Atmospheric
Reaeration
DO Consumed
CBOD Exerted
NBOD Exerted
Discharge from
Reach Upstream
DO
CBOD
NBOD
Discharge to
Reach Downstream
DO
CBOD
NBOD
Immediate Oxygen Demand
Reach of River

Figure 15. Dissolved oxygen river schematic.

$$\begin{bmatrix}\text{DO at}\\ \text{bottom}\\ \text{of reach}\end{bmatrix} = \begin{bmatrix}\text{DO from}\\ \text{upstream}\\ \text{reach}\end{bmatrix} + \begin{bmatrix}\text{DO in}\\ \text{tributary or}\\ \text{wastewater}\end{bmatrix} - \begin{bmatrix}\text{Immediate}\\ \text{oxygen}\\ \text{demand}\end{bmatrix}$$

$$- \begin{bmatrix}\text{Carbonaceous}\\ \text{BOD}\\ \text{exerted}\end{bmatrix} - \begin{bmatrix}\text{Nitrogenous}\\ \text{BOD}\\ \text{exerted}\end{bmatrix} + \begin{bmatrix}\text{Atmospheric}\\ \text{reaeration}\\ \end{bmatrix} \tag{1}$$

$$\begin{bmatrix}\text{Carbonaceous}\\ \text{BOD at bottom}\\ \text{of reach}\end{bmatrix} = \begin{bmatrix}\text{Carbonaceous}\\ \text{BOD from}\\ \text{upstream reach}\end{bmatrix} + \begin{bmatrix}\text{Carbonaceous}\\ \text{BOD in tributary}\\ \text{or wastewater}\end{bmatrix} - \begin{bmatrix}\text{Carbonaceous}\\ \text{BOD}\\ \text{exerted}\end{bmatrix} \tag{2}$$

$$\begin{bmatrix}\text{Nitrogenous}\\ \text{BOD at bottom}\\ \text{of reach}\end{bmatrix} = \begin{bmatrix}\text{Nitrogenous}\\ \text{BOD from}\\ \text{upstream reach}\end{bmatrix} + \begin{bmatrix}\text{Nitrogenous}\\ \text{BOD in tributary}\\ \text{or wastewater}\end{bmatrix} - \begin{bmatrix}\text{Nitrogenous}\\ \text{BOD}\\ \text{exerted}\end{bmatrix} \tag{3}$$

$$\begin{bmatrix}\text{Carconaceous}\\ \text{BOD}\\ \text{exerted}\end{bmatrix} = \left[\begin{bmatrix}\text{Carbonaceous}\\ \text{BOD from}\\ \text{upstream reach}\end{bmatrix} + \begin{bmatrix}\text{Carbonaceous}\\ \text{BOD in tributary}\\ \text{or wastewater}\end{bmatrix}\right] \begin{bmatrix}1-10^{-K_1 t}\end{bmatrix} \tag{4}$$

$$\begin{bmatrix}\text{Nitrogenous}\\ \text{BOD}\\ \text{exerted}\end{bmatrix} = \left[\begin{bmatrix}\text{Nitrogenous}\\ \text{BOD from}\\ \text{upstream reach}\end{bmatrix} + \begin{bmatrix}\text{Nitrogenous}\\ \text{BOD in tributary}\\ \text{or wastewater}\end{bmatrix}\right] \begin{bmatrix}1-10^{-K_N t}\end{bmatrix} \tag{5}$$

where K_1 = First order carbonaceous deoxygenation rate constant
K_N = First order nitrogenous deoxygenation rate constant
t = Time of travel in reach

Volumes of water are visualized as moving downstream as distinct units (or "plugs"). Mixing, dilution, and biochemical reactions occur within the units as they move downriver, but because the system is assumed to be in steady state, the water quality of each unit passing by a given point is exactly like that which preceded it. For this reason, only one incremental volume of water needs to be modeled for the time of travel through the reaches of interest.

Assumptions and Limits

Any model is of value only within limited ranges based upon the restricting assumptions. Assumptions proposed by the US Geological Survey for such a model are considered reasonable for this study and are as follows.

1. Reaches of Rkm 139 to 8 are applicable.

2. Steady state conditions must prevail. The model is applicable to prediction of average daily DO concentration during low flow, high temperature conditions that have been preceded by at least 5, and preferably, 10 days of relatively stable streamflow and water temperature. This condition is approximated by mean August flows of typically dry summers.

3. The streamflow and water temperature must be for low flow between 85 and 255 m^3/s Salem gage and ±3°C of calibration conditions (20° C at Salem, 23°C at Portland), respectively.

4. Channel geometry must be similar to 1973-74 conditions. Isolated dredging or filling do not cause significant differences. In contrast, a 2-m deepening of the Portland Harbor would likely invalidate the present model and necessitate the collection of new channel geometry data.

5. The predominant wastewater loads must be from secondary biological treatment.

6. An approximate balance of DO production and DO consumption between photosynthesis and respiration by aquatic plants must be present (29).

DO problems have been historically most evident in the river's main stem between Rkm 8 and 139, below Salem. The problems occur in late summer when flow is low, temperature and metabolism rates high, and food processing wastes are discharged. Such knowledge allows more effective modeling effort and the use of the simplifying steady-state concept. Below Salem, reach partitioning has been carried out by the US Geological Survey (USGS) for this summer period (30). Above Salem and up tributaries there is less need to model DO. The main stem boundary conditions at Salem are established by routing down oxygen-demanding inputs. This is not done by the DO model, but by supporting models that employ first-order decay expressions for carbonaceous biochemical oxygen demand (CBOD) and nitrogenous biochemical oxygen demand (NBOD).

Hydraulic Data

Good USGS records exist for Willamette streamflow (61). Over 100 stream gaging stations have been established in the Basin. With main stem channel slope, USGS cross-sectional data, and appropriate discharge figures, an effective channel roughness (Manning's n) was determined by a search algorithm for the Willamette channel from Salem to the Newberg Pool.

This estimation of channel roughness allows changes in channel cross-section to be determined for low flow conditions other than those of 1973. In and below the Newberg Pool, channel geometry is fairly constant over the range of low flows. The depth of the Newberg Pool is maintained by Willamette Falls, a natural weir. Channel depths in the tidal portion of the river are controlled by the Columbia which in turn is maintained at fairly constant summer conditions by its own reservoir system.

Travel times from Salem to Rkm 8 obtained from Manning's Equation velocities decreased from approximately 24 to 9 days as Salem discharge varied from 88 to 255 m^3/s, the range of low flow conditions explored in this study.

Willamette Falls

At Willamette Falls oxygen is entrained and dissolved. Multiple routes of overflow at the Falls make the estimation of reaeration difficult. At periods of low flow, the Falls may have very small discharges since water is routed through the fish ladder, hydroelectric turbines, and industrial facilities. For use in the model, a measurement of DO changes from above to below the Falls, August 1973, were employed (30). Reaeration was assumed to vary directly with discharge and DO deficit.

Inputs of Pollution

Point source wastewater discharge data are regularly collected by the DEQ. USGS work in 1973 and 1974 derived an independent point source data set suited explicitly to low flow DO modeling (29, 30). For this study, a data base of point source wastewater dischargers was compiled from DEQ data (9, 10). The DEQ data have historical continuity and would seem naturally to be preferred by State environmental planners. USGS data were used to supplement the point source data base. Where no appropriate data were discovered (typically the case for nitrogenous output from small municipal plants), an estimate was made.

To facilitate the comparison of pollution control strategies outlined in the study objectives, municipal wastewater treatment plant discharges were standardized by plant type. For each class of plants in the Valley, weighted mean CBOD and Kjeldahl N concentration was determined from summer 1973 records. The standardized concentration was then reapplied to each plant's output. Table 5 indicates the standardized effluent concentrations for eight methods of wastewater treatment. Model runs using actual August 1973 discharges and standardized discharges yielded the same main stem DO result.

Industrial wastewater discharges were not standardized as their natures vary widely. One nitrogenous input was given as an unknown industrial nitrogenous load near Albany. Presently its source is unidentified; it was discovered by a nitrogen mass balance of up-and-downstream river samples. Due to poor mixing of summer flow in this reach, however, fieldwork has not correlated this loading to any point source. The input may be due in part to subsurface flows from ponds in the Albany industrial park and/or ammonia traversing the Santiam from a paper mill (30).

Nonpoint pollution data are not easily compiled. For this study where a strategy of nonpoint pollution control was not evaluated, nonpoint inputs were taken to be equivalent point sources at main stem tributary mouths. Tributary municipal and industrial BOD's were routed to the Willamette. BOD's sampled at tributary mouths and not accounted for as decayed residuals from upstream wastewater discharges were treated as nonpoint inputs.

TABLE 5. EFFLUENT CONCENTRATIONS OF BOD AND N FROM MUNICIPAL TREATMENT PLANTS

Plant type*	BOD_5, mg/l	Kjeldahl N as N, mg/l
TFEF	19	10
ASEF	16	12
ASP	18	20
AS	20	20
TF	26	16
L	30	0
P	130	23
ASPL	17	0

*TFEF = Trickling Filter with Effluent Filtration; ASEF = Activated Sludge with Effluent Filtration; ASP = Activated Sludge Package Plant; AS = Activated Sludge; TF = Trickling Filter; L = Lagoon; P = Primary; ASPL = Activated Sludge Package Plant with Lagoon.

TABLE 6. DEOXYGENATION RATE COEFFICIENTS

River reaches	Rate coefficients, base 10, per day	
	Carbonaceous	Nitrogenous
Willamette tributaries	0.06	0.1
Willamette above Salem	0.04	0.2
Salem - Newberg	0.05	0.4
Newberg - Willamette Falls	0.02	0.0
Below Willamette Falls	0.02	0.0

Benthic oxygen demand in the Portland Harbor was modeled as several immediate oxygen demands.

Rate Constants

First-order deoxygenation rate constants for both carbonaceous and nitrogenous biochemical oxygen demand have been determined by the USGS (29). Of particular interest are changes of carbonaceous deoxygenation rate constants from 0.10 - 0.14 (base 10) 20 years ago to 0.03 - 0.06 (base 10) presently. This is believed to result from the primary to secondary improvement of treated discharges.

Deoxygenation rates used in the model were determined by best fit and are given in Table 6. The rates closely agree with the values determined by the USGS independently of DO simulation.

Verification

Three sets of Willamette main stem DO field data exist for August 1973. All three data sets (Figure 16) illustrate the DO decrease, due in great part to nitrification, from Salem to the Newberg Pool (Rkm 140 to 84). The river roughly maintains its DO content in the pool (Rkm 84 to 43), reaerates as it passes Willamette Falls (Rkm 43), loses DO in the tidal pool, and recovers again when at last it is diluted with Columbia flow (not shown).

The ranges plotted in Figure 16 indicate diel oxygen fluctuation and/or sampling variation. It appears that this scatter is fairly regular and does not mask the overall DO profile. Plotted with the field data is the DO profile modeled for the same period. Subsequent model runs with varied discharge and loading provide DO profiles substantially in accord with reported values.

Sensitivity

The Willamette DO profile is generally insensitive to differences in USGS and DEQ point source data. Simulation trials indicated that the main stem DO profile is generally insensitive to altered BOD loadings when such changes are confined to a small number of discharges. Profile changes occur when large numbers of discharges are altered. This significantly affects the use to which the model may be put. Alternative environmental strategies must be modeled as significantly different net discharge loadings. There may indeed be some economic gain obtained by redistributing or reallocating fixed loads among several dischargers, but overall environmental impact is likely to be unaltered.

There exists one exception to the generality of DO's insensitivity to individual discharges. Large nitrogenous loadings in reaches of high nitrogenous deoxygenation rate constant can indeed influence the entire DO profile.

The DO profile is significantly influenced by river travel time. In initial simulation runs in which the lower reaches were not backwater, but rather assumed to flow at normal depth, travel time was unduly short at very low flows (100 m^3/s). As a result, the DO sag too small. The assumption of constant

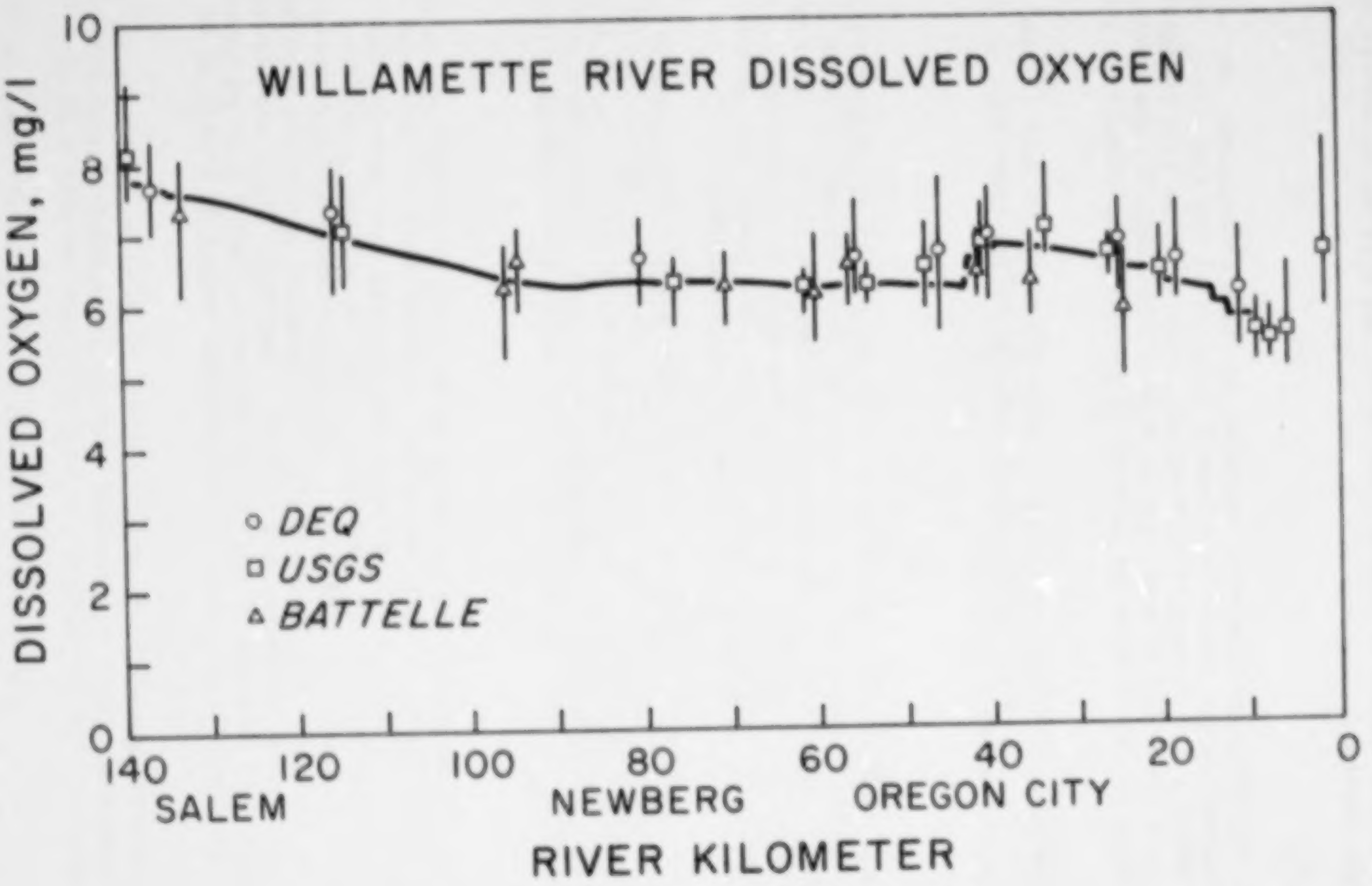


Figure 16. Dissolved oxygen simulation and verification, August 1973 (29, 57).

depth below Newberg corrected this anomaly.

Temperature variations of several degrees centigrade do not greatly alter the results. A 5 to 10°C increase, however, may depress the DO profile. Deoxygenation rate constants that were increased or decreased 10 percent did not greatly alter the DO profile under August 1973 conditions.

A DO Index

It was originally anticipated that three fixed levels of water quality would be considered: above, the same as, and below the DEQ Willamette standards (7 mg/l DO at Salem, 6 at Newberg, and 5 at Portland). In modeling it became evident that to match DO levels, an inordinate set of pollutant loadings would be needed for trial and error solution. Such an expansion of an already multidimensional study is of little general value. Rather, an alternative index of water quality was developed, comparing DO in reaches where sag would be most manifested to the actual DO of August 1973.

To generate a DO index the simulated DO levels are noted for 17 locations systematically spaced through the Newberg and tidal pools. The index is calculated as follows:

$$\text{DO index} = \sum_{i}^{n} \Delta_i / n - zS + K \qquad (6)$$

where Δ_i = DO simulated - DO standard at station i,

S = standard deviation of Δ over sample size n,

n = 17 stations spaced at 5 km from Newberg to Portland,

z = normal statistic for a 90 percent one-sided confidence interval, 1.282 in this case, and

K = correction constant.

The last term in Equation 6 is a constant shifting all values such that the index of actual 1973 conditions is 0 mg/l. To illustrate the meaning of this index, Willamette quality designated by an index of 0.3 mg/l indicates that from Portland to Newberg, 90 percent of the lower river is 0.3 mg/l or more above the DO levels of August 1973.

SUMMARY

A lower main stem Willamette DO model is selected as an environmental expression suitable for this study. The USGS field work and DEQ records provide necessary sources of model data. A model documented in Appendices B and C is developed to relate lower main stem DO detail to Basin-wide pollution control strategy. The model is designed for low-flow, steady-state conditions and summertime loadings of approximately secondary effluents. The Velz reaeration algorithm (Appendix C) satisfactorily accounts for the river's atmospheric oxygen inputs. A DO index is proposed allowing river DO profiles to be compared.

There appears to be significantly different reaction rates of low-flow NBOD exertion in Willamette reaches. CBOD rates are generally low. If travel times are not excessive, much BOD is discharged to the Columbia and not exerted in the Willamette main stem.

Inadequately documented nonpoint source loadings and benthic demands are roughly approximated in the model, but their true natures are largely unknown.

SECTION VII

ECONOMIC MODELING

MODEL SELECTION

Economic analysis provides a link between strategy for environmental quality and energy impact. The energy model expressed in this section translates direct dollar costs for pollution control ("direct" being contract price for treatment plant facilities, annual expenses for reservoir operation, etc.) to a direct energy cost (fuels consumed in construction and operation) and to a total energy cost (energy needed throughout the economy to create and supply the necessary materials for pollution control activity). Economic models for water pollution control strategy were used as estimators of direct dollar charges.

Criteria

Costs were charged to water pollution control if they represented expenses qualifying on tax or DEQ records as those of water pollution control and/or expenses reasonably expected to improve the summer dissolved oxygen quality of the main stem Willamette. Investment in Willamette wastewater treatment facilities and subsequent operation, maintenance, and replacement may or may not bring about an upgrading of the quality parameter of interest, dissolved oxygen. For DO to retain its role as overall water quality indicator, it is necessary to control other potential problems (e.g., suspended solids, metals, nutrients) concurrently. Though these pollution control expenses do not have returns seen in a DO model, they can be assumed to be advantageous to water quality.

Units and Partitioning of Cost

The units selected for economic modeling are constant 1973 dollars. Inflation is corrected for by the Construction Cost Index, as most direct expenses for pollution control are incurred in contract construction (62). This analysis does not address the issue of how inflation may be altered by pollution control expenditures.

Pollution abatement costs may be partitioned into two categories: variable costs and fixed or independent costs. The former class is made of those expenses that can reasonably be approximated as varying continuously and inversely with reduction in pollutant discharge. For variable cost a few more pollutants can be removed with the expenditure of a few more dollars. The second category is that of fixed or independent charges. These typically reflect costs associated with diversion of wastewaters from Willamette outfalls to the Columbia, summertime wastewater detention, land disposal, and prevention of discharges. With such tactics, the characteristics of the waste are of no significance to the quality of the Willamette. The lack of that waste, though, is of potentially great consequence to the Willamette. Willamette quality behaves independently of fixed costs, once invested.

Costs associated with flow augmentation may be treated as variable or independent, depending upon how augmented flow is priced. If a fixed unit expense is attached to summer reservoir release (the common procedure in cost allocation), the charge is subsequently independent of the DO benefits afforded. On the other hand, if a price schedule is assigned to summer augmentation such that resultant water quality enhancement is priced, the charge is variable.

The partitioning of costs into variable and fixed categories helps identify qualitative differences in dollars invested for pollution control. The greater the ratio of variable to fixed dollars invested in a strategy of pollution control, the more flexible the strategy.

WASTEWATER TREATMENT COSTS

Costs for wastewater treatment activity include capital investment and operation, maintenance, and replacement (OMR) expense. Municipal treatment (including municipally treated industrial effluent); interceptor, outfall, and lift station provisions; industrial treatment having separate outfalls; and industrial pretreatments prior to discharge to municipal sewers were the tactics of wastewater treatment considered. Costs not considered included home plumbing, sewer laterals, and the stormwater portions of separated sewers.

Municipal Treatment

Cost functions for municipal waste treatment plants are typically of the form:

$$C = AQ^B \qquad (7)$$

where C = capital or OMR cost,
Q = design plant discharge, and
A, B = constants.

Capital cost models selected from engineering literature indicate that the construction cost of August 1973 Willamette-discharging plants would be $54.1 million (63, 64, 65, 66, 67). This estimation does not include engineering expenses and abandoned portions of operating plants. A 1.24 correction factor was therefore applied to those A coefficients to fit them to the surveyed 1973 $67.2 million sum (3). The total OMR, labor cost, electricity cost, and chemical cost were likewise estimated by exponential functions. Table 7 lists A values corrected for the Basin and B values determined nationally for eight classes of wastewater treatment employed in the Willamette Basin. For these cost coefficients it is presumed that municipal plants are operated on a year-around basis. The DEQ pollution control policy would not allow certain plants to cease operation in the winter when river DO problems are absent.

TABLE 7. COEFFICIENTS A, B FOR COST MODEL (3, 63, 64, 65, 66, 67)

Plant*	$C = \$1000\ AQ^{B\dagger}$				
	Capital construction	Annual			
		OMR Total	Labor	Electricity	Chemical
P	667.2,0.755	43.2,0.587	25.9,0.551	5.9,0.499	8.3,0.578
L	166.0,0.740	7.0,0.554	3.3,0.361	0.0,1.000	0.0,1.000
ASP	206.0,0.440	46.8,0.621	28.7,0.680	11.9,0.497	4.4,0.535
ASPL	226.8,0.469	51.5,0.599	31.5,0.680	11.9,0.497	4.4,0.535
AS	1264.4,0.771	64.4,0.730	38.0,0.767	15.0,0.558	5.6,0.674
TF	1114.2,0.592	42.3,0.621	25.6,0.662	6.5,0.553	6.2,0.510
ASEF	1536.6,0.771	89.8,0.730	42.5,0.767	16.9,0.558	5.6,0.674
TFEF	1386.3,0.592	67.6,0.621	32.0,0.667	8.1,0.553	6.2,0.510

*P = Primary; L = Lagoon; ASP = Activated Sludge Package Plant; ASPL = Activated Sludge Package Plant with Lagoon; AS = Activated Sludge; TF = Trickling Filter; ASEF = Activated Sludge with Effluent Filtration; TFEF = Trickling Filter with Effluent Filtration.

†C = 1973 dollars; Q = Plant design capacity in mgd (1 mgd = 0.0438 m^3/s).

Interceptors, Outfalls, Lift Stations

Wastewater interceptors, outfalls, and lift stations (IOFLS) and OMR cost for capital typically vary with capacity, discharge, length and slope of pipes, and degree of land development. Costs were determined from records.

It is assumed that 1973 Basin plants could be joined by trunk lines following connecting waterways. Flow would be with grade, minimizing lift requirements. To conform to the objective of evaluating treatment costs for 1973 strategies, trunk lines were sized for 1973 discharges, not estimated future flows. It was assumed that sewers proposed for regional alternatives would have the same proportional lift station cost as did the Valley's 1973 interceptor system. OMR costs for interceptors were estimated to be 0.4 percent of construction cost. Lift station OMR costs vary substantially with the unit. Survey results indicated that, outside of Portland, public works agencies spent 4.6 percent of their sewage treatment plant OMR on lift station OMR. This estimator was suitable for this study. To illustrate the relative natures of an IOFLS breakdown, Portland in 1974 spent $175,000 on interceptor and outfall OMR and $191,000 on lift stations. The rest of the Valley spent $175,000 on interceptors and outfalls and $146,000 on lift stations (3).

Industrial Treatment

Industrial pollution control costs can be itemized only on a plant-by-plant, process-by-process basis. Such a breakdown was not required for this study because the assumption was made that over the years the Willamette industrial complex has behaved like one large firm. A general pollution control cost function was then determined. Thirty years of records are available for industrial capital costs, BOD generation, and BOD discharge. Figure 17 shows that capital costs Basin-wide are exponentially related to the percentage reduction of industrial BOD discharge. Figure 17 exhibits a cost discontinuity at a BOD reduction of approximately 0.87. This degree of treatment corresponds to a switch from lagoons to activated sludge for the Basin's major industry, pulp and paper. At 90 percent BOD removal, activated sludge is more cost effective than an extrapolated lagoon system. If the relationship as shown on a linear scale rather than log-log, the curve would approximate the exponential form commonly used to illustrate pollution treatment expense. The discontinuity at the 0.87 level would not be apparent.

The use of such a model imposes limits on strategic pollution control planning. The data from which the model is constructed represent a reasonably consistent and monotonic industrial cleanup. An intraindustrial mechanism was assumed by which pollution cleanup was equitably shared by all the Basin's firms. For a particular environmental strategy with a net industrial discharge, the total cost can be estimated from the industrial cost model, and specific changes in wastewater discharge allocated in a manner proportional to current loadings. Costs for tactics of decreasing one plant's discharge and increasing to the same extent that of another could not be modeled by this approach. Such tactics are inconsistent with given goals of best practicable or available treatment for all dischargers. In cases where unique industrial changes are of interest, total industrial cost estimates would have to be modified.

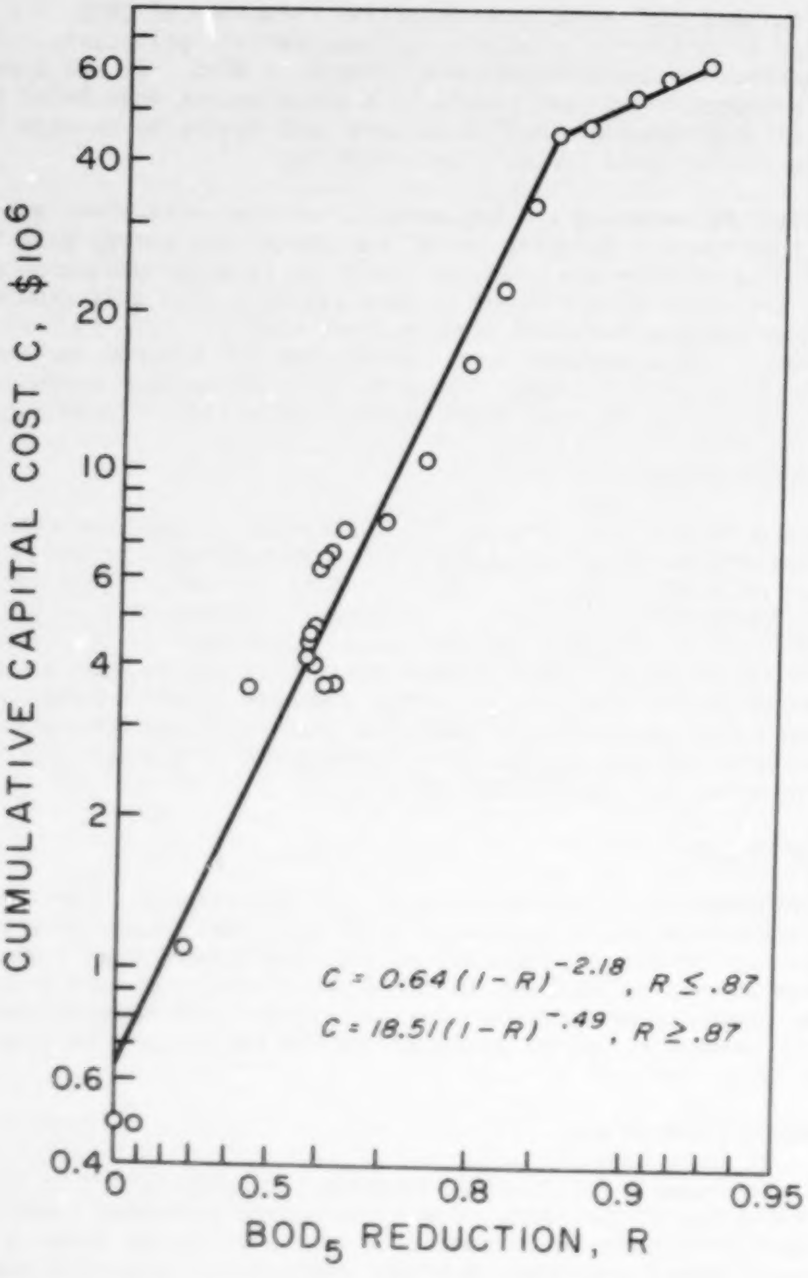


Figure 17. Industrial expenses for water pollution control, Willamette Basin (3, 25, 26, 27).

It was assumed that across the industry, reduction of CBOD is a reasonable estimator of reduction of other, less documented pollutants. A CBOD reduction is accompanied by a proportional change in NBOD. It was assumed that the unknown nitrogen input near Albany is a point source industrial discharge. If the cost of NBOD removing facilities were paid by the Basin-wide industry, this nitrogen source could probably be controlled.

Industrial OMR expenses are typically integrated with other production costs. The best overall estimate stems from industrial survey data that indicated that $3.3 million was spent by the firms as water pollution OMR expenses (3). OMR costs were assumed to directly vary with pollution control capital costs. Several Portland firms incorporated in Basin records discharge to the Columbia. These expenses were summed from DEQ records and recorded in the fixed or independent category. Records of Basin capital costs indicated approximately 3 percent of industrial capital costs fell into this category.

Industrial Pretreatment

Forty-five Basin industries in 1973 discharged to combined municipal systems. The end-of-line treatment expenses are incorporated in the municipal data and thus were not recounted. However, many of these industries practiced pretreatment before release to the sewers. Survey data on pretreatment revealed that capital expenses and OMR annual costs were of the same magnitude. Some firms may have no pollution control equipment, per se, but account some of their production OMR costs as pollution control. Total capital investment was estimated to be approximately $800 000; yearly OMR was $400 000. These costs were divided between Willamette and non-Willamette discharge in the proportions determined for municipal plants.

Abandoned Facilities

Costs of abandoned plants were taken from DEQ records. These facilities are typically package plants removed from service when sewers were extended from central facilities. In regionalization, some plants were removed from service and other plants expanded to serve the demand. In such a case, the value of the removed plant was recorded as a fixed, independent, abandoned facility. No salvage value was assumed. No OMR was associated with abandoned facilities.

LOW FLOW AUGMENTATION COSTS

A cost attributable to flow augmentation for water quality control may be derived in either of two ways. The first method estimates benefits foregone by other reservoir beneficiaries when flow is augmented for water quality control. A second method uses costs derived from expense data from the reservoirs. By allocation, a share of reservoir cost is assigned to the reservoir beneficiary, water quality.

Benefits Foregone to Other Water Uses

Willamette water uses have been identified in Section IV. Alterations in benefits due to changes in instream flow were investigated as part of an evaluation of strategies. Table 8 indicates the probable effects on various water uses as a result of decreased and increased summer flow augmentation. Effects stem from both altered discharge and resultant water quality. A discussion of the construction of Table 8 is found in Appendix D. As indicated in Table 8, waste disposal and irrigation were the water uses most tangibly related to low flow augmentation. The competitive relation of the two uses, one instream, one consumptive, provided a benefits foregone estimation of augmentation's value for water quality. From Appendix D, \$53 000 per m^3/s represented a liberal extrapolation of what instream flow might be so worth.

Small or negligible complementary augmentation benefits are realized by several other water-related activities, but values are difficult to determine and are likely to be insignificant. In some cases, flow augmentation for DO control provides no real increase in benefits for other augmentation uses but does give a measure of added protection.

Charges to Reservoirs

Willamette low flow augmentation is recognized to be an effective strategy for water quality maintenance. Costs of such regulation are incurred in construction and operation of the Corps' multipurpose reservoir projects. A model of water pollution control's share of these expenses brings forth a problem different than the problems encountered in estimations of treatment costs or benefits foregone. In those models, data were often sparse, but the data dealt with unique objectives. A dollar spent for a treatment plant was a dollar spent for pollution control. For multipurpose reservoirs, a dollar spent may be an investment for recreation, hydroelectric power, and low flow maintenance. The charge for low flow control may yield improved navigation, irrigation, and pollution control. The problem is one of cost allocation to reservoir beneficiaries, only one of which is water quality. As discussed in Section IV, water quality is generally not an authorized reservoir purpose, and thus not assigned a cost in Corps' documents.

This investigation must depart from a viewpoint of no-cost flow augmentation for water quality control. If flow augmentation is allowed to compensate for some treatment, a strategy of explicit interest in this study, flow augmentation must be priced. Otherwise, as a seemingly free good, there is no reason economically to opt for anything less than the hydrologic upper limit of dilution flow. The problem of strategy would be moot.

The separable cost-remaining benefits method is used in the allocation of costs for Federal multipurpose water resource development, pursuant to a 1954 agreement among the Corps, Federal Power Commission, and the Department of the Interior. This method provides that each project be charged no less than the costs incurred only due to its inclusion in the project, no more than its benefits, and between these limits, a proportionate part of the savings stemming from the multiple-purpose project.

As developed in Appendix E, a reservoir charge to water quality control was allocated as:

TABLE 8. PROBABLE EFFECTS OF ALTERED LOW FLOW MAINTENANCE, WILLAMETTE RIVER*

Water use	Decreased low flow maintenance		Increased low flow maintenance	
	Lower discharge	Lower water quality	Higher discharge	Higher water quality
Municipal, Industrial	-	-	+	+
Irrigation	++	+	--	-
Navigation	-	0	+	0
Hydroelectric Power	-	0	+	0
Flood protection	-	0	+	0
Recreation	- River + Reservoir	- River	+ River - Reservoir	+ River
Waste disposal	--	--	++	++
Fish, wildlife	-	-	+	+

* Key: 0 Same benefits of river use.
+ Increased benefits of river use.
- Decreased benefits of river use.
Single sign indicates a general case, probably not significant on the Willamette.
Double sign indicates a significant, tangible relationship on the Willamette, potentially suited to economic analysis.

$$C = 27\,A_{WQ} / (98 + A_{WQ}) \qquad (8)$$

where C = annual charge, millions of dollars, and

A_{WQ} = alternative annual cost of water quality control to yield a specified level of summertime DO in the lower Willamette, millions of dollars.

Because benefits of multipurpose reservoirs in effect subsidize one another, this cost model is sensitive to the value of hydroelectric power produced by the reservoirs. As shown in Appendix E, if power is valued at twice its 1973 price, the denominator in the equation would become $(109 + A_{WQ})$, decreasing the charge to water quality.

SUMMARY

A set of economic models were developed to provide costs in direct 1973 dollars for two approaches to water pollution control in the Willamette: treatment and low flow augmentation. Treatment costs included capital and operational expenses for municipal plants, interceptors, outfalls, lift stations,and industrial waste treatment and pretreatment. Treatment costs were categorized as variable, incrementally influencing Willamette water quality; or independent, having a fixed effect on the Willamette.

Low flow augmentation costs for water quality were expressed in two manners: the benefits potentially foregone to irrigation, or a portion of reservoir cost attributable to augmentation.

SECTION VIII

ENERGY MODELING

INTRODUCTION

In this section an Input/Output energy model is developed to express the energy requirements for Willamette pollution control strategies. There are several limits of the Input/Output approach and these limits, along with their implications for energy modeling, are discussed.

In most technical studies, a theoretical expression for modeling is rigorously developed in the body of the report and the details and procedures necessary to carry out the model are relegated to an appendix, or not published altogether. In this study, the emphasis is reversed. Input/Output analysis is currently a standard econometric method. An example of Input/Output development is included in Appendix F for illustrative reference. Expanding the ability to put to use the theory that already exists, rather than development of more complex models, is needed if energy modeling is to become a useful analytic perspective. Thus, this section focuses on a use of an existing Input/Output energy model.

DIRECT, INDIRECT, AND PRIMARY ENERGY

Strategies of environmental control require both direct and indirect energy. Direct energy is used as high grade fuel (coal, oil, gas) or power consumed in the final step of pollution control, e.g. electricity to build and run wastewater treatment plants. Indirect energy is required as high grade fuels consumed to mine the iron, to forge the steel, to fabricate the equipment, and to produce pipes or chemicals needed by the plant. If material flow can be traced from raw materials to final products, and if at each step of material transformation the consumption of high grade energy is known, indirect energy embodied in the final product can be estimated.

To assess the energy impact of pollution control alternatives, both direct and indirect energy requirements are of interest. Direct needs are of principal concern within a region where power is in short supply. An energy need for environmental control may compete with the need of some other energy-consuming activity, say industrial production. Indirect needs are of major concern to the economy as a whole, of which the region is but a part. Since it is probable that a trace of material flow will extend from region to the encompassing economy, much of the indirect energy requirements may be experienced outside of one region. If national energy stock is insufficient to meet all demands, the indirect energy requirement imposed by one region is energy consumption foregone by consumers in other regions. If the region imposing the indirect national demand also must compete nationally for its own direct energy supply, the indirect needs then compete against the direct needs of that very region.

To unify energy analysis of a large system, it is necessary to reduce energy costs to a common unit. The fossil fuel equivalent "primary" joule is selected as such a measure. This unit represents a joule of energy obtained from coal, oil, or natural gas. Where hydroelectricity or nuclear electricity is consumed, its fossil fuel equivalent is considered, i.e., the units of fossil fuels required to generate that quantity of electricity. Hydroelectricity taken for pollution control forces other power users to turn to fossil sources, thus all energy consumed is considered to be effectively a demand upon primary sources.

Primary energy cost for any activity is the equivalent final cost of that activity to the world's fossil energy stock. This cost is variously called the total cost or the direct plus indirect cost.

The term "total" energy cost has another popularized meaning that should be distinguished from the usage in this study. Total energy cost is at times considered to be the net flux of all types of energy quantified on a fossil fuel equivalent basis (51). Such accounting credits energy value to coal, gross plant production, sunlight, dollars, information, ocean currents, in short, the inputs to world systems. The "primary" unit employed in this investigation is less general. Primary energy is derived from fossil reserves or generated from hydroelectric or nuclear plants. Primary energy is transformed in the production sector of an economy and consumed as heat and light in households, mechanical friction in factories, fuel for autos, etc. Thus primary energy represents a subset of broadly-defined "total" energy.

INPUT/OUTPUT ANALYSIS

Input/Output analysis (I/O) is an application of general equilibrium theory to empirically interrelated activities. An open system is modeled as linearly interdependent sectors of production and consumption; coefficients relating each sector's output to inputs are assumed to be fixed. Perturbations of output from the total system yield shifts of production within the system. These internal shifts reflect the sector inflows and outflows necessary to satisfy new exogenous requirements, endogenous mass balance, and constant input-to-output factors. I/O analysis has been shown to be suitable for modeling flows of goods, money, pollutants, and energy (68, 69, 70, 71).

The basic I/O model for energy demand is illustrated in Appendix F. Included is a discussion of the double counting problem, a consequence of recounting transformed energy.

Model Expression

As developed in Appendix F, the solved I/O energy model is of the form:

$$\underline{E} = \underline{\varepsilon}\,\underline{Y} \qquad (9)$$

where $\underline{E}$ = the primary energy consumed directly and indirectly,

$\underline{Y}$ = the final demand in dollars for goods, and

$\underline{\varepsilon}$ = a dollar-to-energy transformation, the "primary" energy coefficient.

In addition, direct energy demand can be expressed as:

$$\underline{E} = \underline{R}\,\underline{X}$$

where $\underline{E}$ = the energy directly consumed,

$\underline{X}$ = the total production in dollars of goods, and

$\underline{R}$ = a dollar-to-energy transformation, the "direct" energy coefficient.

I/O coefficients ε and R have been calculated by Herendeen and others for the U.S. economy in 1967 (72, 73). These values may be modified for a 1973 Willamette Valley study if conceptual limitations, time dependence and regional variance from the national I/O model are considered.

Conceptual Limitations

The energy I/O model is limited by assumptions and conventions. Technology and energy coefficients ε and R are not independent in any real economic system, although they are assumed so in the model. Fossil fuel equivalents of hydroelectric or nuclear power introduce a technological component into the primary energy unit. Dollar flow in times of unstable monetary systems, producers' prices rather than those of consumers, exclusion of capital formation from transaction data, technical coefficient variability, and no economies of scale all impose limits on I/O scope. Nonetheless, Input/Output analysis is econometrically useful for studies where projections do not extend far into the future and perturbations of demand are moderate.

Figure 14 in Section V traces a variety of energy flows in and through the Willamette Basin. Like much of the State energy policy discussed in that section, I/O deals with industrial production. An I/O model can only be used in a "total" energy analysis as partial specification of the industrial subsystem. I/O itself does not provide insight into the dynamic aspects of economic behavior.

Time Dependence

Energy I/O national models have been constructed semi-independently for the United States in 1963 and 1967 (75, 76). The latter analysis reflects improvement in technique and scope. Of 352 non-energy model sectors, 281 appear to have decreasing primary energy-per-dollar intensity. The mean energy-per-dollar change is negative, potentially resulting from dollar inflation and technical development. The mean change does reflect an economy of expanding dollar flow and limited energy, an overall trend that is anticipated to continue.

A similar test for trends can be made from lumped figures for national energy consumption and gross national product. Such a check weights industrial sectors by their production. Using current dollars, such a calculation yields an approximate 2 percent annual decrease in energy intensity from 1963 to 1967 and a near 3 percent downward rate from 1967 to 1973. This again agrees with expected development in an energy-depleting economy. The apparent net rate change with time (the rate change from minus 2 to minus 3 percent) may stem from a spiral of energy-based dollar inflation. As world fossil reserves are rapidly being depleted, it is probable that the minus 3 percent rate will continue in its downward trend. As this study deals with conditions of 1973 only, the approximately 3 percent deflation rate was judged as empirically proper to apply to 1967 total energy (per dollar) coefficients.

If energy coefficients were projected to future years, an improved theory of energy deflation would be required. A 1967-to-1973 correction for I/O coefficients ε and R is a 6-year compounded 3 percent deflation applied to 1967 energy/dollar ratios. The issue of energy inflation is illustrated in the following example. Note that although the energy cost rises, the dollar cost rises more rapidly.

Cost of hypothetical project in 1967	\$1 000
1967 I/O primary energy coefficient	100 MJ/\$
Energy cost from 1967 I/O	100 000 MJ
Cost of same project in 1973	\$1 771
1973 I/O coefficient ($100 \times (1-0.03)^6$)..	83 MJ/\$
Energy cost in 1973	147 519 MJ

Regional Variation

I/O is best applied to a well disaggregated economy in which each sector receives a large portion of inputs from industries also within the economy. Subnational I/O models often have aggregated sectors with industries lumped enough together such that intersectional material flow, the crux of I/O analysis, is not trivial.

Two economic I/O regional models applicable to the Willamette region have been developed. An I/O economic model exists for the Willamette Valley, containing only four sectors. It affords little chance for analysis of specific sectors. It is of value in identifying the Basin's general import-export structure and for limited general economic projections (77).

A State of Oregon model exists for 1963 (78). In this model Oregon's industries are grouped into 29 sectors. The study is primarly an illustration of method rather than a definitive planning effort. A general check for regional disconformity can be abstracted from this model. State intraindustrial direct and indirect dollar requirements (diagonal $(I-A)^{-1}$ in Appendix F) can be compared to those of the nation. If they appear to be somewhat alike, the overall impact of a dollar spent in Oregon is similar to the overall impact of a dollar spent in the national economy.

Two sectors in the Oregon model are of particular interest to pollution control strategy: maintenance and repair construction (MRC); and electricity, water, gas, and sanitary services (EWG). Thre is no sector in the Oregon model corresponding to construction. The State-modeled MRC sector produces $1.00746 of output per $1 sold to final demand. Corresponding national coefficients for two sectors combined to form the State classification are 1.00186 and 1.00737. For state EWG, the requirement is $1.00225. The agreement between the two I/O tables is reasonable. In these two pollution control activities, the regional and national economies behave somewhat alike.

Because pollution control in Oregon appears to be economically similar to that of the nation, it is hypothesized that the Basin's environmental regulation is in energy terms like that of the nation, especially when extra-Basin indirect impact is considered. A national energy I/O model is thus useful for regional study. Additional confirmation of the suitability of national energy I/O models was obtained from Willamette pollution control survey data. Direct energy requirements for construction and OMR were derived from detailed material-use records and fell typically within ±50 percent of the I/O direct prediction, the scatter anticipated nationally (70).

SECTOR ASSIGNMENT

In Section VII direct economic costs for water pollution control were modeled. The estimated costs correspond to the productions X and Y used in I/O energy analysis. The problem now remains of assigning to the pollution control costs the appropriate ϵ or R transformation coefficients.

Table 9 lists activities of Willamette River pollution control, the national I/O sectors to which they were assigned for energy modeling, and the resultant transformation coefficients, corrected to 1973. A discussion of how specific sector assignments were made, and how coefficients were determined to encompass the Basin's industrial production follows.

Pollution Control Activity

No economic sectors of the national I/O energy model are uniquely suited to activities of treatment plant construction, reservoir operation, and the like. The national breakdown of 368 sectors tends to disperse parts of such activities into various classifications. OMR costs for wastewater treatment might fall into: maintenance and repair construction other than for non-farm residential buildings (national I/O sector 1202); water and sanitary services (6803); or local government enterprises other than passenger transit or electrical utilities (7903). Each of these sectors reflects partly the pollution control activity of interest and much activity not of concern.

From intermediate energy I/O tables, discriminatory information may be abstracted about the 368 categories (73). The direct energy coefficients, R, are of particular interest. Survey data indicates that Willamette sewage treatment plants are almost exclusively powered by electricity (3). Coal is of zero direct use. Of the three likely I/O sectors, 1202 is primarily directly fueled by petroleum, 6803 consumes coal directly, and 7903 is mainly electrically powered. The latter sector, therefore, was judged as best incorporating OMR for Willamette sewage treatment plants.

TABLE 9. INPUT/OUTPUT DIRECT AND PRIMARY ENERGY COEFFICIENTS

Activity	Construction			OMR		
		MJ/1973 dollar			MJ/1973 dollar	
	Sector	Direct	Primary	Sector	Direct	Primary
Municipal treatment	1103	9.81	58.49	7903	52.11	89.91
Interceptors, outfalls, lift stations	1104	14.39	39.22	7903	52.11	89.91
Industrial pretreatment	1103	9.81	58.49	*	35.34	81.22
Industrial treatment	1103	9.81	58.49	*	35.34	81.22
Reservoirs	1105	12.48	40.76	7804	16.29	31.10

* National sectors combined to approximate Willamette industrial production.

Reservoir OMR, a Federal activity not exclusively assigned an I/O sector, is energetically approximated by the miscellaneous Federal activity sector 7804, a sector unintensive in operational energy needs.

The construction energy requirements for industrial pre-treatment tactics were assumed to be approximately equal to those of municipal treatment. The energy requirements for OMR pre-treatment tactics including process modification should be approximately those incurred in regular industrial production. Weighting 32 Basin industries by value of output and identifying from I/O sectors the appropriate industrial energy requirements, a Basin-industry OMR energy requirement was calculated.

Interceptors, outfalls and lift stations OMR was assumed to be similar in energy intensity to municipal plants. Per OMR dollar, more energy is directly purchased in these activities than in any other general pollution control measure.

Energy requirements for capital construction are easier to estimate than those for generalized OMR. Independent of I/O analysis, direct energy requirements for various construction activities have been estimated (80). Information specific to the pollution control tactics can then be used in place of the nationally based I/O direct coefficients for regional construction energy intensity.

Construction energy direct requirements were estimated from both literature and Willamette Valley construction records (3, 80). Treatment tactics were best identified in the I/O sector 1103, construction of public utilities. Again, industrial treatment works were assumed to require the same input mix in construction as did municipal works. Interceptors, outfalls, and lift station construction were similar in energy inputs to the highway construction sector 1104. Reservoir construction was placed in the category of new construction, other, 1105.

Irrigation Foregone

The option of valuing flow augmentation as irrigation foregone lends itself to an I/O conversion, but the result is different than those of dollar expense. Increased irrigation may yield an increase in the Basin's economic activity. In Appendix D, a \$53 319 per m^3/s direct value is assigned to Willamette abstraction over the irrigation season. This figure, treated as benefit foregone if flow is withheld from the fields, may be I/O translated to primary energy not spent for increased agricultural production. Thus, water not diverted for irrigation represents both income not realized for Valley farmers and demand not exerted on primary energy resources.

Whereas the dollars foregone might legitimately be seen as a cost, the energy not mined cannot be truly interpreted to be a benefit. No energy impact was credited to non-irrigation.

Comparisons

The magnitudes of I/O coefficients in Table 9 reveal relative energy costs of various pollution control activities. These values can be compared intuitively. In direct construction, energy intensity is lowest for treatment facilities; gasoline and electricity to build a treatment facility represent only a small part of a contractor's expense. Interceptors and reservoirs, earthmoving endeavors, are higher in fuel per dollar intensity. Based on the ratio of direct to primary energy for construction, treatment has greater spinoff energy impact; the longer economic chain associated with the mechanical and high-grade material inputs requires a greater overall energy input. For interceptor and reservoir construction, roughly 30 percent of the primary energy impact is realized directly. For treatment facilities, the ratio is approximately 17 percent.

In the OMR columns, the greatest direct energy requirements are exerted by municipal facilities. Industrial treatment requires less direct power, assuming production can be modified for wastewater control. Reservoir operation requires a relatively small amount of power. Though municipal and industrial tactics have different direct OMR coefficients, the total coefficients are more nearly the same. This suggests that once a dollar is spent, it is likely to eventually trace similar paths. Much of the OMR municipal and industrial dollars are spent for energy-intensive chemicals. The reservoir primary coefficient is low. A dollar here is less likely to be spent for a series of energy-expensive materials; it is more likely to be payment for labor and quickly dissipated to the household sector.

SUMMARY

An energy Input/Output model is selected to express the energy impact of the Willamette water quality control strategy. The model transforms dollar expenses for various pollution control activities to both direct ("on the job") and primary ("from the earth") energy costs.

I/O models can be used to describe the economy best if supplies and demands are steady. I/O is not suited for projections of energy impact when technology is rapidly changing. This was not judged to be a difficulty for this study since most treatment and construction technology of 1967, the base year for the I/O model, was similar to the treatment and construction technology of 1973, the year under study. With correction for overall dollar-to-energy inflation, the I/O national energy model yielded dollar-to-energy coefficients suitable for the Willamette case in 1973.

Appropriate sectors for Willamette pollution control activities are identified. The resultant I/O coefficients revealed that per dollar of environmental control expense, the energy impact varies with activity. This provides an energy criteria for evaluation of pollution control strategies. The determination of which strategy can purchase a given level of water quality with the least amount of energy is explored in the subsequent section.

SECTION IX

ANALYSIS

INTRODUCTION

In previous sections, the Willamette Basin and its interrelated environmental, economic, and energy resources have been discussed (Sections III to V). Models have been developed expressing environmental, economic, and energy consequences of water pollution control (Sections VI to VIII). This section defines the range of pollution abatement strategies over which the consequences of such strategies are modeled, summarizes the modeling procedure, and then summarizes the results of analysis.

TREATMENT-AUGMENTATION MATRIX

Wastewater Treatment Levels

Eight alternatives for wastewater treatment are specified. Tables 10 and 11 list by treatment alternative municipal, industrial, nonpoint and benthic Willamette oxygen demands. Designated A through H in order of pollutant removal degree, the treatment alternatives do not represent every step of the regulation, but rather an increasing series of pollution abatement tactics. Level A represents a heavily polluted river, not improved since the 1950's. Level H indicates a complete abatement of oxygen-demanding point discharges. Level D represents the actual base period of August 1973.

Levels A and H are not reasonable alternatives for water pollution control in the 1970's. Neither extreme is modeled well, as assumptions of environmental condition (e.g. secondary-type wastes in river) or technological consistency (e.g. energy coefficients suited to 1973) are likely violated. Nonetheless, these two treatment extremes give perspective to consequences of middle degree treatment alternatives deemed to be more reasonable.

Levels C, D, E, and F represent secondary treatment tactics consistent with recent and near future probable Oregon regulation. Level G represents a major effort at industrial nitrogen control, an area of regulation only presently being effectively incorporated into DEQ planning (81). In Appendix G a description of each treatment level is given.

Flow Augmentation Levels

Four levels of low flow augmentation are used in the water quality modeling. A Salem discharge of 88 m^3/s represents a typical unregulated Willamette dry year low flow, as shown in Figure 7. A flow balance for August 1973 in-

TABLE 10. SUMMARY OF TREATMENT LEVELS

Strategy	Treatment level	Municipal plant types*	Industrial BOD$_5$, KjdN removal	NPS	Benthic
Less Treatment	A	P, L	52% , 0%	August 1973 loading	August 1973 loading
	B	P, L	81% , 23%		
	C	AS, TF, L	90% , 30%		
1973	D	L, ASPL, ASP, AS, TF, ASEF, TFEF	94% , 33%		
More Treatment	E	L, ASPL, ASP, AS, TF, ASEF, TFEF	95% , 46%		83% August 1973 loading
	F	ASEF, TFEF, ASPL, ASP	95% , 46%		
	G	ASEF, TFEF, ASPL, ASP	95% , 90%		
	H	Unspecified	100% , 100%		

* TFEF = Trickling Filter with Effluent Filtration; ASEF = Activated Sludge with Effluent Filtration; ASP = Activated Sludge Package Plant; AS = Activated Sludge; TF = Trickling Filter; L = Lagoon; P = Primary; ASPL = Activated Sludge Package Plant with Lagoon.

TABLE 11. SUMMARY OF RIVER LOADINGS

Treatment level	Municipal		Industrial		NPS		Benthic	Total	
	BOD$_5$	KjdN	BOD$_5$	KjdN	BOD$_5$	KjdN	IOD	BOD$_5$	KjdN
A	42998	7540	149039	24120	16860	943	1361	208897	32603
B	42998	7540	59616	18629	16860	943	1361	119474	27112
C	12457	5742	29808	16799	16860	943	1361	59125	23484
D	12252	5737	19872	16189	16860	943	1361	48984	22869
E	6613	5080	15897	12951	16860	943	1134	39370	18974
F	5764	3780	15897	12951	16860	943	1134	38521	17674
G	5764	3780	15897	2473	16860	943	1134	38521	7196
H	0	0	0	0	16860	943	1134	16860	943

dicates that without augmentation, this discharge would have taken place. Statistical analysis gives the same result (61). Discharge above 88 m^3/s may therefore be designated as augmentation derived from reservoirs.

The August 1973 mean discharge of 186 m^3/s represents augmentation under the present water quality control strategy. This discharge is that called for by the Corps to facilitate navigation and the State Water Resources Board to protect fish life (35). A 126 m^3/s discharge represents a level of decreased augmentation. Boating or fisheries would not significantly suffer at this flow if water quality were maintained. An upper limit to augmentation from existing reservoirs is estimated to be 255 m^3/s. This discharge would call for reservoir rule curves to be modified for rapid, late-summer drawdown.

With 8 levels of treatment and 4 levels of flow, 32 alternatives for pollution control can be investigated. This 4 x 8 matrix provides the basis for environmental, economic and energy comparison of water quality control strategies.

Response Surfaces

The response surface is a graphical alternative to data representation in matrix form. A response surface can be envisioned as a 3-D surface suspended above a 2-D base. The base here is a Cartesian plane defined by coordinates of wastewater treatment and river discharge. The height of the response surface above any point on this base represents the environmental, economic or energy consequence corresponding to the treatment-augmentation pair. The surface may be displayed in the same manner as contour lines on a topographic map.

Advantages of the response surface representation over a matrix display are several:

1. More data may be represented than only those pertaining to certain matrix columns and rows,

2. Data may be visually interpolated,

3. Trends may become apparent, and

4. The response surfaces may be directly employed in subsequent decision making analysis.

ENVIRONMENTAL ANALYSIS

Table 12 lists by discharge and treatment the simulated mean DO deviations, the standard deviation of those differences, and the 90 percent index defined in Section VI. In cases where the standard deviation is small, the simulated DO profile is roughly parallel to the 1973 standard. Where the deviation is large, the index is substantially lower than the mean difference; this results from the sensitivity of the index to the worst 10 percent case. The H option with a flow of 255 m^3/s is eliminated as offering nothing in incremental DO benefit above that achieved with 186 m^3/s. Three options of low

TABLE 12. DO MEAN DIFFERENCE, STANDARD DEVIATION, AND INDEX (mg/1)

Mean August discharge m^3/s	Treatment level							
	A	B	C	D	E	F	G	H
255	-1.03	-0.16	0.41	0.50	0.74	0.81	1.37	
	0.69	0.30	0.05	0.06	0.10	0.11	0.08	
	-1.91	-0.54	0.35	0.42	0.61	0.67	1.27	
186	-2.46	-1.01	-0.13	0.00	0.36	0.43	1.15	1.62
	1.29	0.53	0.08	0.00	0.05	0.06	0.14	0.20
	-4.11	-1.69	-0.23	0.00	0.30	0.35	0.97	1.36
127		-2.43	-1.02	-0.77	-0.25	-0.16	0.80	1.60
		0.83	0.19	0.11	0.05	0.05	0.29	0.19
		-3.49	-1.26	-0.91	-0.31	-0.22	0.43	1.36
88			-2.17	-1.75	-0.98	-0.91	0.38	1.46
			0.34	0.29	0.20	0.17	0.41	0.27
			-2.61	-2.12	-1.24	-1.13	-0.15	1.11

TABLE 13. TREATMENT, AUGMENTATION AND TOTAL ANNUAL COSTS ($\$ \times 10^6$, 1973)
Flow Augmentation Cost Allocated

Mean August discharge m^3/s	Treatment level							
	A	B	C	D	E	F	G	H
255	16.14	19.41	27.57	30.11	35.64	37.45	38.33	
	3.66	2.14	5.93	6.00	6.41	6.55	8.87	
	19.80	23.68	33.50	36.11	42.05	44.00	47.20	100.00
186	16.14	19.41	27.57	30.11	35.64	37.45	38.33	
	1.76	2.14	2.73	3.04	4.31	4.28	7.87	
	17.90	21.55	30.30	33.15	39.95	41.73	46.20	100.00
127	16.14	19.41	27.57	30.11	35.64	37.45	38.33	
	0.56	1.28	2.03	1.89	0.74	0.34	4.51	
	16.70	20.69	29.60	32.00	36.38	37.79	42.84	100.00
88	16.14	19.41	27.57	30.11	35.64	37.45	38.33	
	0	0	0	0	0	0	0	
	16.14	19.41	27.57	30.11	35.64	37.45	38.33	100.00

treatment and low flow are eliminated because river quality would go anaerobic.

Figure 18 transforms the index variable of Table 12 into a response surface. The gradient of DO is positive, but decreases from left to right and bottom to top. With increase of treatment and/or augmentation, there appears to be decreasing returns of environmental improvement. Since the 1973 DO was typically 6 mg/l (Figure 16), the flattening of the surface at higher elevations is explained in part by an asymptotic approach to the DO saturation limit.

ECONOMIC ANALYSIS

Modeled treatment costs for treatment levels A to G are tabulated in Appendix H. Treatment cost for level H, "complete" treatment, is projected from general, national figures discussed in Appendix G. Treatment total costs, A to H, may be read from the bottom line of Table 13.

As noted in Section VII, flow augmentation costs might be determined by two methods: a charge for water diverted from irrigation, or a charge allocated to reservoir expenses. Flow is valued in both manners.

Augmentation Cost Allocated

Table 13 includes within each treatment-augmentation pair an allocated charge for water quality flow maintenance. This charge is determined by using Figure 18, the DO index response surface, to find the treatment level that would provide the same index quality at no augmentation. The cost of this treatment less the cost of treatment with augmentation is the alternative cost to augmentation. Allocated according to the separable cost, remaining benefit method proposed in Appendix E, Table 13 results. The allocated cost of augmentation generally increases from left to right. Exceptions to this trend occur where alternative costs are small.

The sum of treatment and allocated augmentation charges is the dollar response surface, Figure 19. The move from level G to H is the most costly of the given steps in pollution control.

A general assumption of pollution control strategy is here reiterated. In lieu of flow augmentation, point source wastewater treatment facilities would be constructed to mitigate dry year summertime DO depletion. In compliance with law, these facilities would be operated throughout the year, not solely during low flow periods.

Augmentation Unit Priced

If augmentation is valued at a fixed unit price, say \$5/af (af = 1233 m^3) as suggested in Appendix D and Section VII, Table 14 is obtained. Although treatment costs are as before, augmentation costs are not related to treatment savings, but rather to discharge level alone.

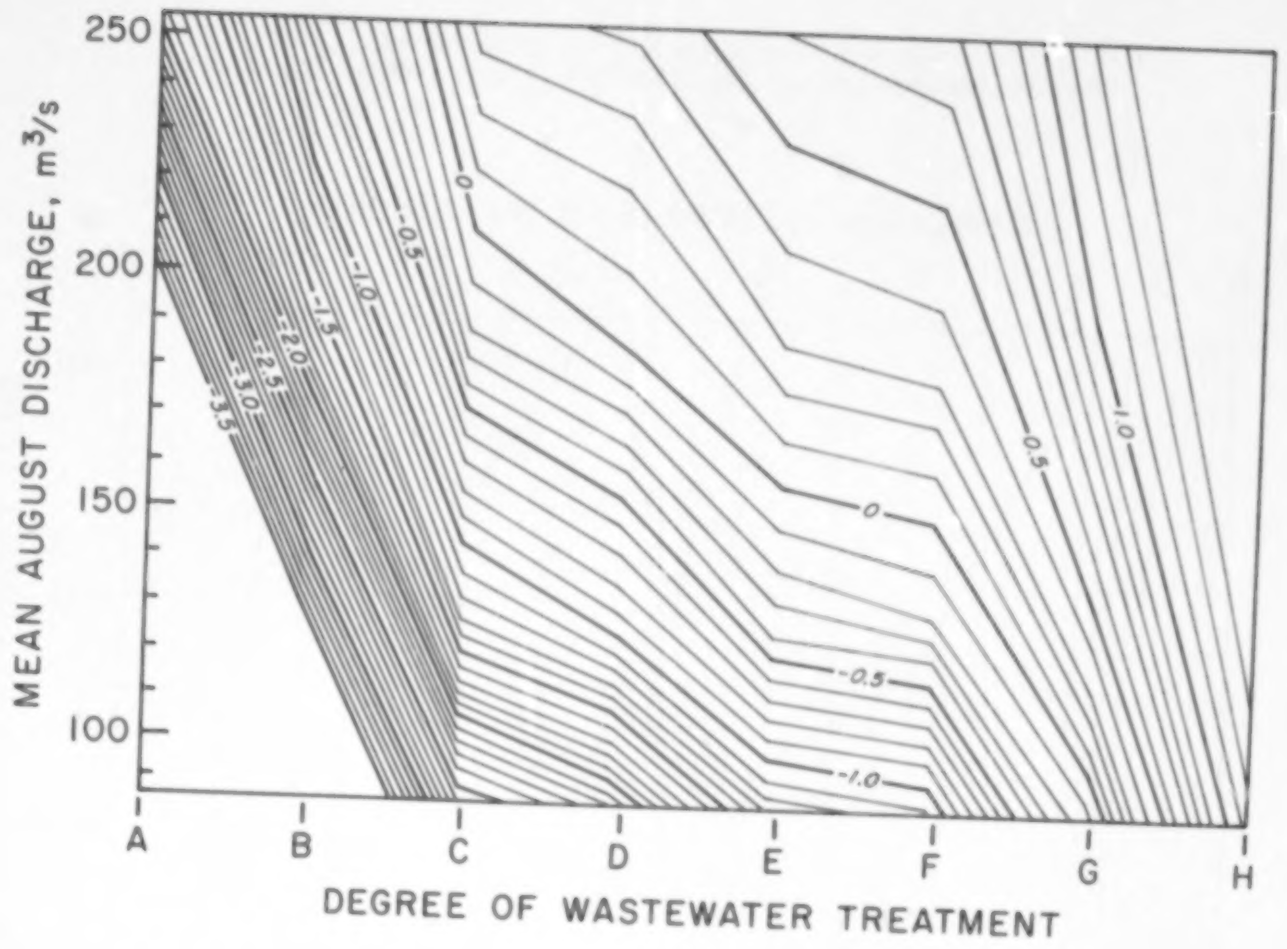


Figure 18. DO index response surface, August 1973, mg/1.

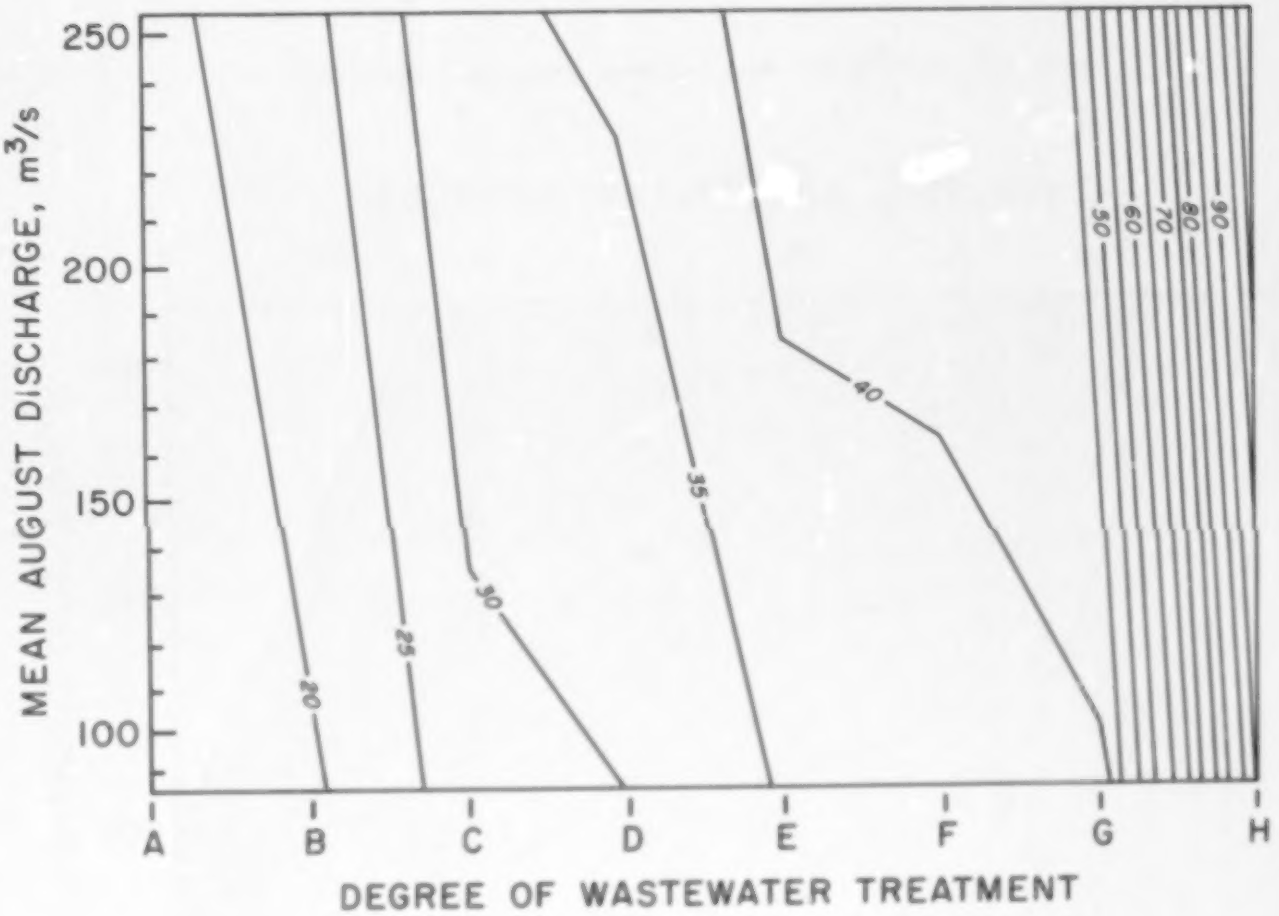


Figure 19. Annual cost of water quality control response surface, flow augmentation cost allocated, $ x 10^6.

TABLE 14. TREATMENT, AUGMENTATION, AND TOTAL ANNUAL COSTS
($ x10^6, 1973)
Flow Augmentation $5/af

Mean August discharge m^3/s	Treatment level							
	A	B	C	D	E	F	G	H
255	16.14	19.41	27.57	30.11	35.64	35.45	38.33	
	8.86	8.86	8.86	8.86	8.86	8.86	8.86	
	25.00	28.27	36.43	38.97	44.50	46.31	47.19	100.00
186	16.14	19.41	27.57	30.11	35.64	37.45	38.33	
	5.19	5.19	5.19	5.19	5.19	5.19	5.19	
	21.33	24.60	32.76	35.30	40.83	42.64	43.52	100.00
127	16.14	19.41	27.57	30.11	35.64	37.45	38.33	
	2.10	2.10	2.10	2.10	2.10	2.10	2.10	
	18.24	21.51	29.67	32.21	37.74	39.55	40.43	100.00
88	16.14	19.41	27.57	30.11	35.64	37.45	38.33	
	0	0	0	0	0	0	0	
	16.14	19.41	27.57	30.11	35.64	37.45	38.33	100.00

Figures 20(a) and (b) and 21(a) and (b) illustrate cost response surfaces for water quality control at four prices of augmentation. In Figure 20(a), flow is free, thus imposes no cost on environmental strategy. Figure 20(b) plots the data of Table 14, the $5/af condition. In Figure 21(a) and (b), flow is valued at $10 and $20/af, respectively. As price rises, the response surface becomes more controlled by degree of augmentation.

Decision Making and Expansion Paths

The DO and economic response surfaces provide a basis for cost-effective environmental regulation. If the DO surface and a cost surface are superimposed, a path from left to right can be identified wherein for any given total annual charge, the maximum attainable DO index is achieved. Likewise, for any given DO, the corresponding cost is minimized. The procedure is standard in microeconomic analysis: treatment and augmentation are factors of production; the DO index and cost response surface contours are output and input isoquants, respectively; and the cost effective route of DO improvement is the expansion path (82).

Expansion paths, therefore, represent the efficient allocation of resources yielding incremental improvement toward an objective. If pollutant production were to always remain at 1973 levels and regulation were solely directed toward maximization of instream DO index, an expansion path on a treatment-augmentation plane would indicate how treatment and augmentation should be simultaneously employed. In this study, no assumption is made that 1973 waste production is fixed over time. Therefore, a treatment-augmentation expansion path here represents not a continuous-in-time best route for DO maximization, but rather a focus of points useful for evaluating the tactics of 1973. The closer the actual 1973 strategy is to the expansion path, the more cost efficient is that strategy.

Expansion paths are identified for DO control at $0, $5, $10, and $20/af charges for augmentation. The results are shown in Figure 22. Several generalizations may be drawn from that figure. If water were free, logical DO control would call for immediate maximization of augmentation and then step by step construction of treatment facilities. If water not used for augmentation were valued at $20/af, the cheapest DO improvement comes from treatment through level G before augmentation is initiated. These two extremes are respectively expressed by the expansion paths following the upper and lower boundaries of Figure 22.

With water priced at $5/af, augmentation should be maximized before treatments B, C, and D are purchased, but as steps E, F, and G are added, some augmentation can be cut back, saving its charge. At $10/af the expansion path is similar, but augmentation should be held at an intermediate value and then reduced.

All paths indicate that if the Basin were regulated near treatment level H, augmentation should be maximized, since the DO returns from augmentation would be much greater than the incremental DO returns from such high and costly marginal wastewater treatment.

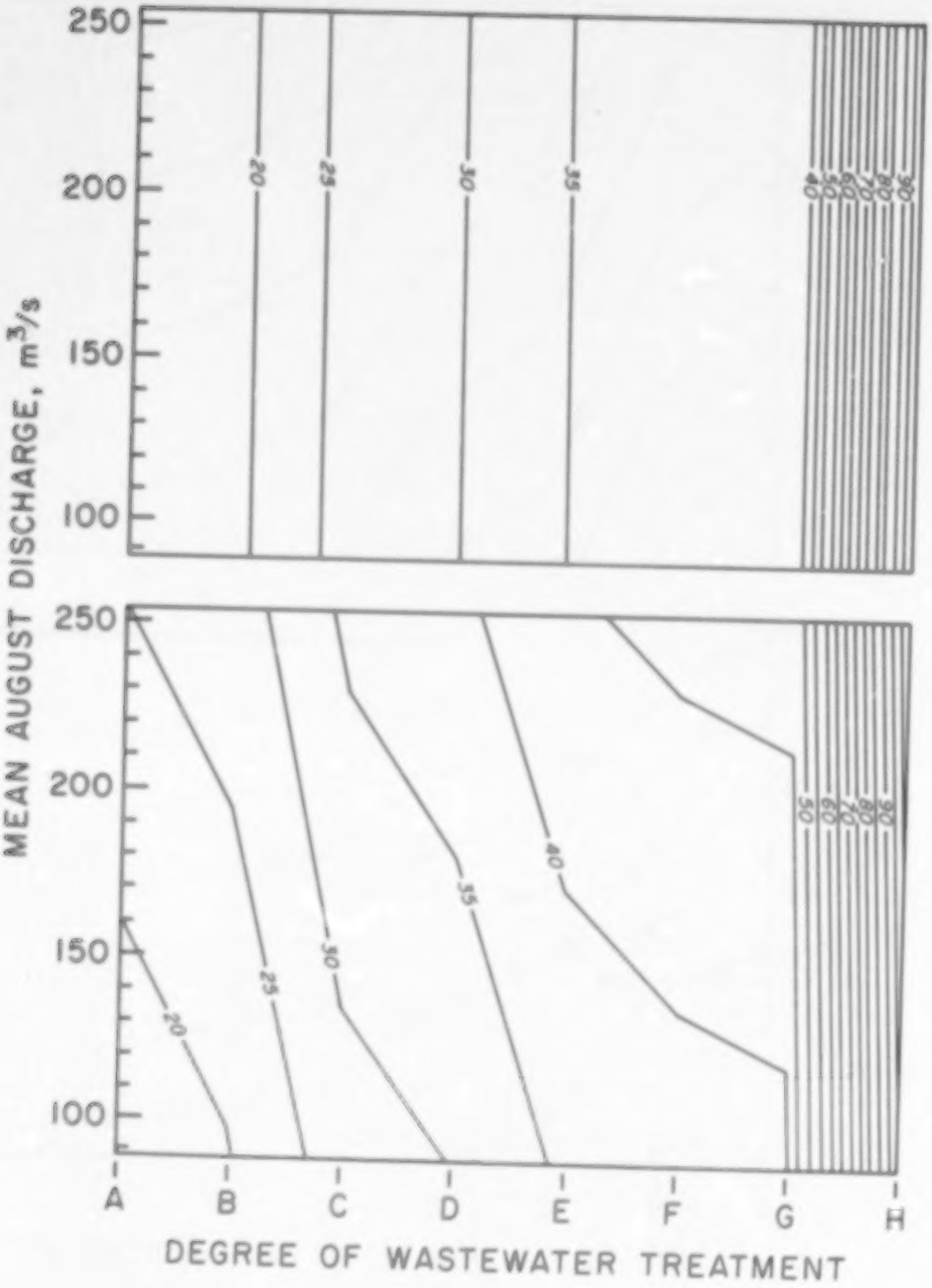


Figure 20. Annual cost of water quality control response surfaces, flow augmentation (a) \$0/af and (b) \$4/af, \$ x 10^6.

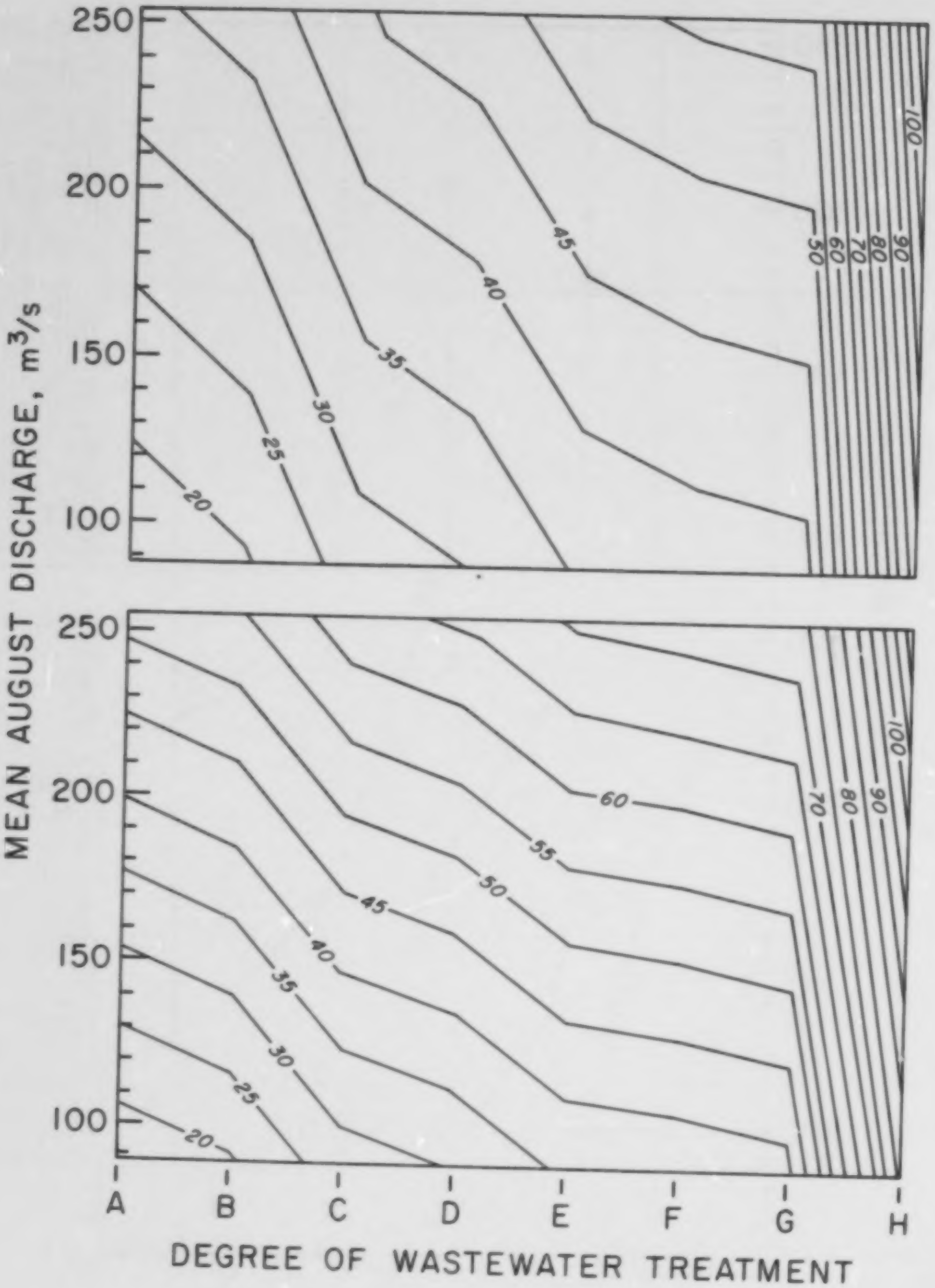


Figure 21. Annual cost of water quality control response surfaces, flow augmentation (a) \$10/af and (b) \$20/af, \$ x 10^6.

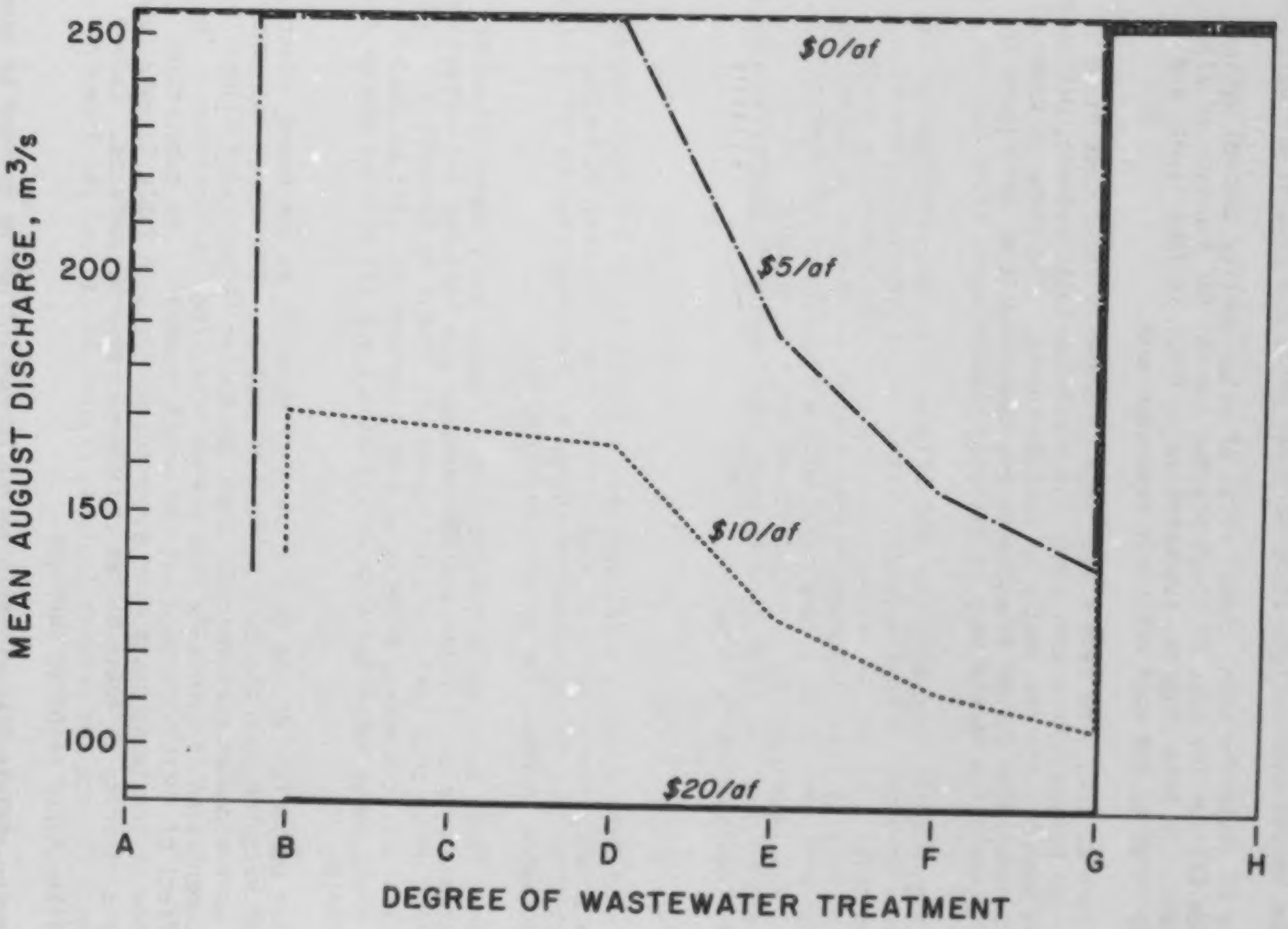


Figure 22. Expansion paths for water quality control, flow augmentation at four prices.

What is shown by an expansion path is the most efficient ascent up the cost and environmental quality response surfaces. What is not shown is how steep that route might be. Somewhere, gains (or losses) in environmental quality will be halted when society deems marginal costs and returns are balanced.

Figure 23 plots the total annual costs of water quality control against the DO index (a) for the case of fixed pricing and (b) for the case of allocated charges. In both figures, augmentation is fixed at four levels and varies determined by the cost efficient expansion path.

In Figure 23 (a), flow levels alternate in order of total cost as DO is improved. The bottom line always plots the expansion path gradient, defining the minimum boundary for the family of cost-DO curves. The changing order of the fixed augmentation curves illustrates the same results as did Figure 22. Levels of augmentation should vary in efficient upgrading of river quality.

From Figure 23(b), augmentation cost allocated is cost-efficient at the maximum level of flow. From Figure 23 a rather broad observation may be drawn: the total cost per DO return is basically of the same shape whether augmentation cost is cost allocated or unit priced, or whether pollution control is cost efficient or is accomplished with a fixed level of augmentation. As the DO index is brought up to -1, costs do not rise sharply. As the DO index is raised to 0 or +1, costs tend to soar. Willamette DO control strongly exhibits decreasing returns to scale.

ENERGY ANALYSIS

The Input/Output energy model applied to the costs of pollution control yields the primary energy costs of that control. As indicated in Section VIII, the allocation method for augmentation charge is preferred over an irrigation benefits foregone approach for primary energy study.

Table 15 lists total dollar, direct costs, and primary energy costs for the 8 treatment levels. Capital and OMR expenses are included for comparison. The data from which this table is constructed are listed in Appendix H. Tables 16 and 17 indicate the energy effects of flow augmentation, cost allocated. Figure 24 plots these tabulated data as (a) direct and (b) primary energy response surfaces.

A brief comparison of the dollar costs (Figure 19) to the energy costs (Figure 24) revealed much the same pattern of contour. The energy isoquants of Figure 24 were somewhat more vertical than the dollar isoquants of Figure 19, because augmentation is generally less energy intensive than treatment. The overall effect of this difference was not great, however. The substantial predominance of treatment costs over augmentation costs in Table 13 gave reason to the similarity of total dollar and energy response surfaces. Except for the units (direct and primary joules), Figures 24 (a) and (b) likewise revealed like-shaped response surfaces.

An energy-efficient expansion path for DO control can be derived as were the dollar-efficient paths of Figure 22. This step was bypassed because of the similarity of the energy surfaces, Figure 24, to the dollar surface of

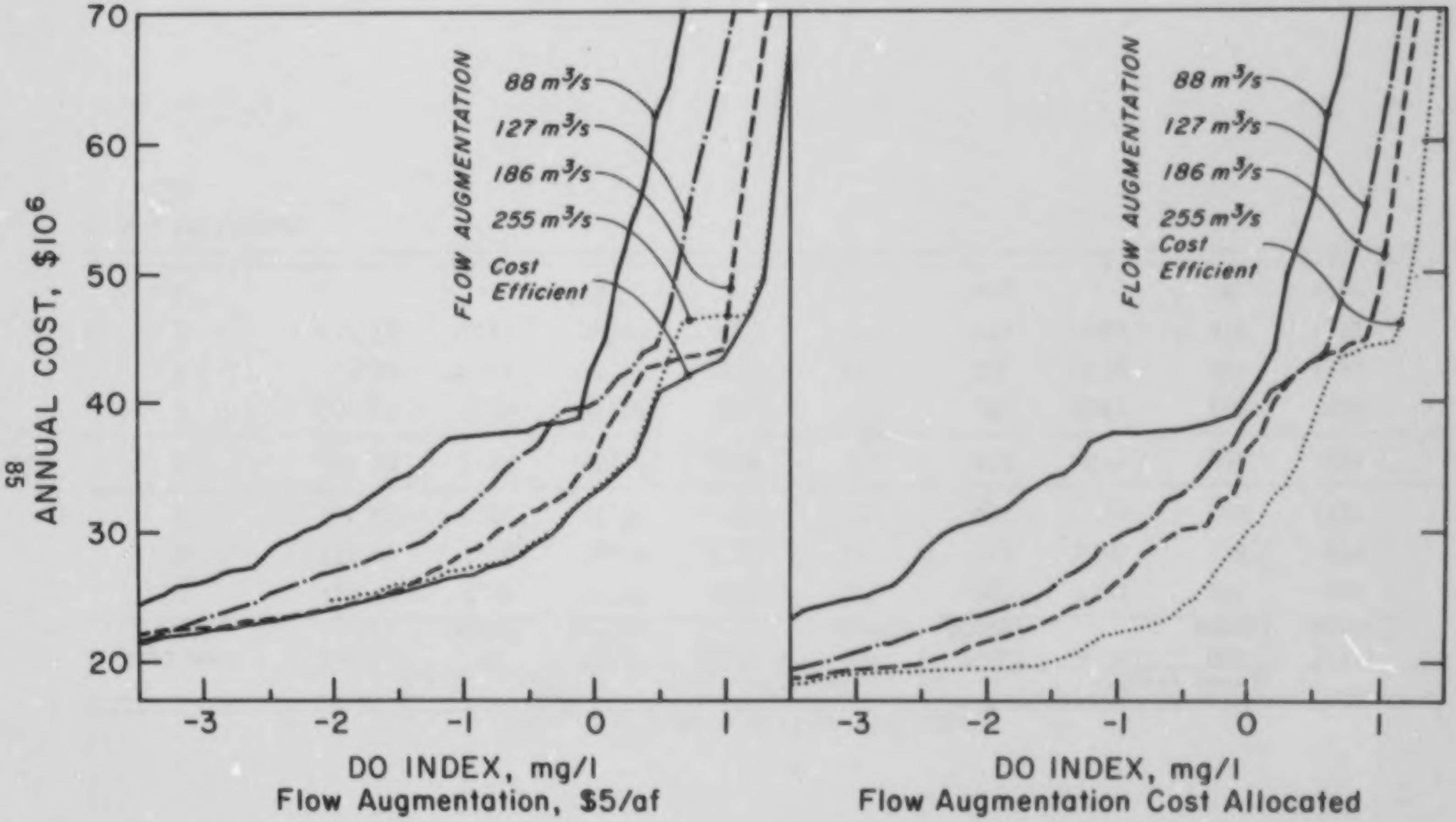


Figure 23. Annual cost versus DO index, flow augmentation (a) $5/af and (b) cost allocated.

TABLE 15. SUMMARY OF TREATMENT COSTS

Treatment level	$ x 10^6, 1973			Direct energy, TJ			Primary energy, TJ		
	Capital	OMR annual	Total annual	Capital	OMR annual	Total annual	Capital	OMR annual	Total annual
A	154.72	4.41	16.14	1928	218	282	7324	391	669
B	174.96	5.30	19.41	2127	249	323	8508	463	800
C	233.65	7.28	27.57	2702	328	431	11940	628	1137
D	248.33	8.16	30.11	2846	363	473	12799	701	1253
E	303.62	9.29	35.64	3477	415	550	15661	800	1476
F	312.66	10.31	37.45	3566	467	606	16190	891	1593
G	317.10	10.67	38.33	3609	479	620	16449	919	1635
H	*	*	100.	*	*	1600	*	*	4000

* Not estimated.

TABLE 16. TREATMENT, AUGMENTATION, AND TOTAL ANNUAL DIRECT ENERGY COSTS (TJ)

Mean August discharge m^3/s	Treatment level							
	A	B	C	D	E	F	G	H
255	282	323	431	473	550	606	620	
	47	55	76	77	82	84	113	
	329	378	507	550	632	690	733	1600
186	282	323	431	473	550	606	620	
	22	40	34	37	54	53	99	
	304	363	465	510	604	659	719	1600
127	282	323	431	473	550	606	620	
	7	16	25	24	10	4	57	
	289	339	456	497	560	610	677	1600
88	282	323	431	473	550	606	620	
	0	0	0	0	0	0	0	
	282	323	431	473	550	606	620	1600

TABLE 17. TREATMENT, AUGMENTATION, AND TOTAL ANNUAL PRIMARY ENERGY COSTS (TJ)

Mean August discharge m^3/s	Treatment level							
	A	B	C	D	E	F	G	H
255	669	800	1137	1253	1476	1593	1635	
	149	172	238	241	257	262	359	
	818	972	1375	1494	1733	1855	1994	4000
186	669	800	1137	1253	1476	1593	1635	
	71	126	109	120	174	169	315	
	740	926	1246	1373	1650	1762	1950	4000
127	669	800	1137	1253	1476	1593	1635	
	22	51	81	75	30	13	181	
	691	851	1218	1328	1506	1606	1816	4000
88	669	800	1137	1253	1476	1593	1635	
	0	0	0	0	0	0	0	
	669	800	1137	1253	1476	1593	1635	4000

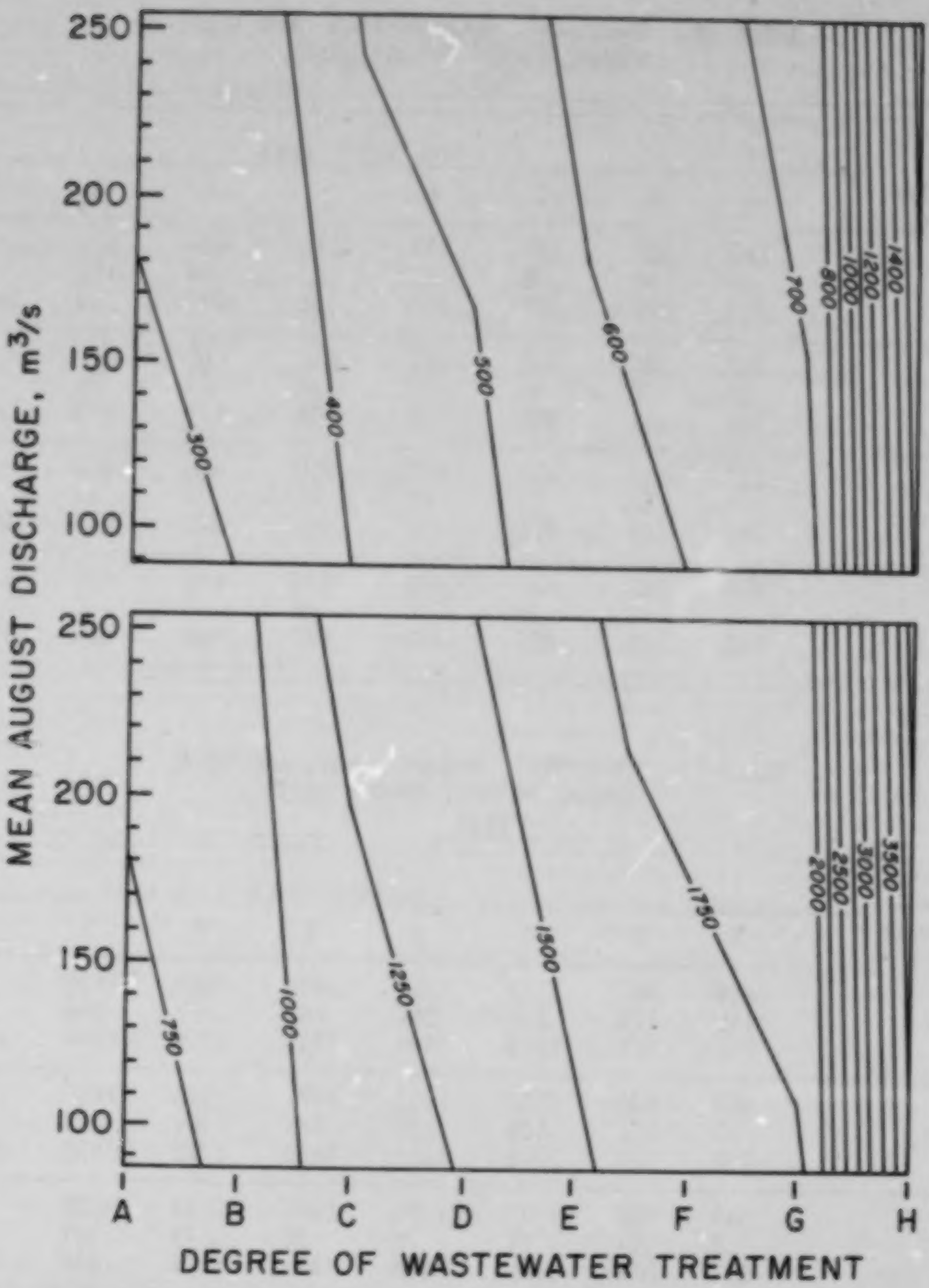


Figure 24. Annual (a) direct and (b) primary energy cost of water quality control response surfaces, TJ.

Figures 20(a) and (b). The energy contours were intermediate in slope between those where water is free and where it is valued at $5/af. Decisions based on energy alone will thus be like those based on dollars alone if water is in that price range. The energy-efficient combinations of flow and treatment lie between the $0 and $5/af paths of Figure 22.

SUMMARY

To bring together environmental, economic, and energy analysis of Willamette pollution control strategies, a 4 x 8 matrix of augmentation and wastewater treatment levels was developed. Augmentation varied from none to a level approximately 70 percent above that of the study year 1973. Point source treatment level varied from minimal to "complete" with emphasis given to degrees near conventional secondary technology.

For fixed levels of augmentation and treatment, the resulting river DO was simulated and indexed. Using the DO index for cost allocation, or simply assigning a unit price to flow augmentation, total costs for water quality treatment-flow strategy were estimated in dollars, and direct and primary energy. Results were converted into response surfaces, providing interpolated DO, dollar, and joule estimations for strategies other than those defined in the initial matrix.

The DO index and dollar response surfaces were used to develop cost-efficient steps of a strategy seeking improved DO. If augmentation were valued at a low unit price or cost allocated, augmentation should be maximized before increased secondary treatment facilities are purchased. If flow were highly valued for uses competitive with low flow augmentation (not now the case, but a possibility in the future), there would be justification in reduced flow maintenance in favor of increased treatment of pollutant loadings.

Whatever the means of augmentation pricing and whatever the mix of flow and treatment, the cost per incremental gain of DO begins to rise rapidly in the vicinity of 1973 treatment levels. This is in part due to the exponential costs of advanced wastewater treatment technology and in part due to the saturation limit of DO.

SECTION X

DISCUSSION

In the preceding section the analysis was drawn together in a graphical manner; this section deals with interpretation of that analysis. In this interpretation, the economic and energy consequences of DO quality protection are shown in a larger perspective. Discussion focuses on three issues. In what latitude can the modeled results be accepted? What do such results have to say about on-going efforts for Willamette water quality control? How does the cleanup satisfy the State environmental, economic, and energy policies?

VALIDITY OF ANALYTIC RESULTS

The modeled environmental, economic, and energy consequences for alternatives of water pollution control strategy are reasonable and informative. They may, however, be hastily interpreted in an unreasonable and misleading manner. Discussion in Sections V, VI and VII centered on the necessities of model selection suitable to the problem at hand and model employment compatible with assumptions and limits. At this point these items are reviewed. Each has bearing on the credibility that can be assigned to the modeling output.

The Study Period

August 1973 provided a base period in which water quality strategies could be compared. This period is well documented, marks significant restoration of a river, and illustrates the role of low flow augmentation for water quality control. Conclusions concerning water quality control for 1973 may be in part transferable to decision making in subsequent years if late summer streamflows are low, if waste production is not too different from that of 1973, if treatment technology is similar, and if the objective of environmental management is essentially one of mitigating DO problems of the lower Willamette during summers of low flow years.

DO Simulation

If the water quality model of this study is improper, subsequent error would be passed along into the cost allocation procedures. As the profiles of DO do appear to be satisfactory for periods of summer low flow in which the waste discharges are approximately of a secondary quality, such an error does not seem to occur. However, some treatment levels substantially below or above secondary quality were investigated; the accuracy of the DO predictions are unknown. (The DO profiles even at these extremes, however, seem to be reasonably consistent with historical records and conceptual projections). The environmental model is useful, but not substantiated outside of its assumed range. DO simulation in the near 1973 range can be assumed to be within

5 percent of true Willamette DO. DO simulation at the extreme treatment levels may be 10 or 15 percent in error.

Cost Estimation

Because inflation of the 1970's has rapidly altered cost data, the cost models developed in Section VII are only valid for 1973. Even within 1973, the models do not express the variation of prices for projects of the same size. The best information that the cost models yield deals with total sums over the entire Basin.

In the same manner that additional latitude should be given to DO predictions for treatments far from secondary, broader variability should be associated with cost estimates for treatment technologies significantly different than those commonly in use in 1973. In Figure 19, the dollar response surface slopes may be a little steeper or flatter at the sides. This, however, is a fortunate place to find a possible poor estimation. Because reasonable strategies for the 1970's do not include such low or very high degrees of waste treatment, costs associated with such treatment levels are not overly critical for decision analysis.

The allocation of reservoir costs is based upon the hypothesis that if summertime DO levels were not improved by flow augmentation, DO would be improved by treatment plant construction and operation. Additionally, the point source treatment would be directed toward management of infrequent summertime conditions, but would entail plant upgrading that would be employed throughout the year. Thus, alternative costs to augmentation are weighed heavily. This weight is the consequence of typical pollution control legislation imposing plant-type technical solutions and achievable quality discharge standards.

Energy Estimation

I/O energy estimates carry along errors of economic modeling and in the case of flow augmentation, of DO simulation. Thus energy impact is the least accurately modeled consequence of water pollution control.

The Input/Output energy model is an expression developed from aggregated data. I/O results are generally considered to be within 50 percent of actual case by case values (79). The more accurate uses of the I/O energy model deal with broad economic activities, defined by distinct I/O sectors. Water pollution control is not well partitioned by such general sectors. Therefore, even the 50 percent accuracy estimate may not be broad enough.

For general regional study, however, I/O energy estimates are of more value than such error allowance might indicate. Differences in direct energy intensity (Table 9) are both intuitively reasonable and roughly substantiated by regional survey data (3). Primary energy intensities are broadly derived from the national economy and thus should be a good estimate of mean energy-dollar relationships.

The I/O limitations and the subjectivity of sector assignments brought forth in Section VIII preclude I/O energy study outside of a system where economic steady state is approximately maintained and where data exist on interindustrial transactions. Like all models, I/O cannot reveal truly new information, but rather provides additional perception into what is already identified.

In this study where investigation deals with a well-documented, short-term base period, results appear reasonable for regional analysis of energy differences between water pollution control alternatives where direct and primary energies define the scope of energy planning.

IMPLICATIONS FOR WILLAMETTE POLLUTION CONTROL

Pollution Control Standards

The selection of waste water treatment levels for the Basin (Table 10) reflects the DEQ's emphasis on achieving high secondary quality of discharges. Issues of nitrification are not pursued with the vigor applied to suspended solids. The flat gradient in the central section of Figure 18, the DO response surface, reveals that DO gains do indeed decelerate as wastewater treatment is directed towards goals other than dissolved oxygen quality.

Dissolved oxygen standards (5 mg/l in the tidal reach, 6 mg/l in the Newberg Pool, 7 mg/l Newberg to Salem, and 8 mg/l above Salem) were not met only in the Newberg area in 1973. Significantly, the lower standard at Portland was achieved. If the standards were modified, the rationale of the stairstep values should be examined. In reaches where rapid nitrification is expected, DO limits might perhaps be reduced by as much as 0.5 mg/l. In the lower Willamette, where deoxygenation rates are low, DO limits might be increased, by as much as 1 mg/l, to better reflect what pollution control can effectively attain.

The cost versus DO index curves (Figure 23) indicate that future DO improvement may become less attractive as an environmental goal. By either of two pricing schemes for augmentation, pollution control costs rise with DO gains. Of significance in these cost curves is the domain of DO indices where costs begin to soar. The upturn generally begins in the -1 to 0 interval. From both the dollar and energy perspective, diseconomies of scales are substantial for continued DO improvement. Pollution control standards should strive to maintain a DO to protect aquatic life, but the standard established is a reflection of public priorities, not precise calculation.

A Unit Price for Low Flow Augmentation

Because cost allocation is not undertaken every time a decision must be made concerning low-flow reservoir releases, a general estimator for the economic value of augmentation is of use to the planner. In Appendix D, a $5/af price is assigned to instream augmentation as irrigation benefits foregone. The cost allocation of reservoir costs, however, allows this estimation to be improved.

If the allocated cost response surface in Figure 19 is compared with surfaces derived from fixed charges in Figures 20 and 21, the allocation outcome most closely resembles the response surface in Figure 20(b), the \$5/af value. This provides some substantiation of the \$5/af estimate. The allocated surface, however, is somewhat less deflected by augmentation than is the Figure 20(b), \$5/af value. A \$3/af unit price might be a somewhat better allocated valuation for flow augmentation. This would assume less net gains resulting from expanded irrigation (a proper correction, see Appendix D) and allow a cost allocation for reservoirs more in conformity with original authorization. This unit price for augmentation assumes that water quality is judged by low-flow summertime DO levels in the lower Willamette (return period, 25 years). The price is appropriate only to drawdown from existing reservoirs.

Evaluation of 1973 DO Control

At \$3/af, the expansion paths of Figure 22 reveal that the cost-effective approach to DO control is one in which low flow augmentation is generally maximized. It appears that if flow were valued at approximately \$8/af, the actual 1973 treatment-flow mix (D, 186 m^3/s) would lie on an expansion path and thus be efficient. The 1973 management thus overvalues water used to maintain water quality. The Willamette, however, is not regulated solely for dollar efficiency. Low flow level has been roughly fixed whereas treatment technology has been continuously stepped up. Augmenting flow to the 186 m^3/s level and adding treatment necessary for DO is a reasonable strategy for environmental control. The reservoir release, a tactic politically difficult to alter, is set at an intermediate value and then river DO is tuned with the easier to modify variables, the treatment plants.

Pertinence to Future Regulation

The expansion paths of Figure 22 give a degree of economic justification to the DEQ's contention that augmentation may be curtailed in the future. It does appear that low flow could be efficiently reduced if raw waste production were held at 1973 levels (this might assume moderate economic development balanced with an increased conservation ethic), and if treatment were upgraded to a high secondary (level G) quality. It appears, however, that if wastewater treatment needs advance beyond this level, flow at any reasonable price would be best used to dilute wastes in the river.

The 1973 level of augmentation (186 m^3/s) seems again to be one of moderation. Until future loadings, constraints on waste treatment, DO targets, and irrigation benefits are more certainly foreseen, there is little reason to substantially alter the reservoir release curves and increase possible future corrections.

Energy Considerations

A final implication for pollution control results from the energy perspective. The question arises whether decisions drawn on a direct or primary energy basis will be different than those based on dollars. In the previous section, both direct and primary energy costs were represented over the plane of treatment-augmentation possibilities by response surfaces similar to the dollar surfaces for either case where flow was cost allocated or priced \$3/af. If so priced, the 186 m^3/s release was shown to be low. Thus this level of flow is low also in energy terms, both direct and primary. This sort of confirmation should not be interpreted as an independent check on environmental strategy. The dollar-to-energy coefficients that I/O develops are generally similar enough to each other (Table 9) that the conclusions drawn from this type of energy considerations are not likely to be substantially unlike those derived from dollars. Because reservoir dollars affect energy somewhat less than treatment dollars (Table 9), energy-efficient decisions should call for somewhat more augmentation at given treatment than would cost-efficient decisions if any differences should arise in the selection of environmental strategy.

Given the very approximate nature of I/O coefficients and the dependency of I/O conclusions upon dollar cost figures, I/O energy study for Willamette regulation should be seen as potentially informative, but should not be expected to greatly broaden more conventional economic analysis.

IMPLICATIONS FOR BASIN POLICY

The response surfaces and expansion paths can serve as a guide for efficient decision making, but they imply nothing about where development should cease. Just because it may be prudent to add a little more flow augmentation before a little more wastewater treatment, this is not a proof that either should be added. The extent of water pollution control must be tied to the objectives of the system for which water pollution control is just one activity. Those objectives direct policy. As emphasized in Section V, such policy may be viewed from many perspectives, among them environmental, economic, and energy. In this section, the analytic interpretation of Willamette pollution control strategy is put into such perspectives.

Environmental Policies

Upgrading Willamette DO has been a prime objective of water management in the Basin. The DEQ's Water Quality Management Plan specifies DO river standards that were substantially met in 1973 (10, 27). Post-1973 regulation is roughly mapped as a shift to the lower right on the treatment-flow possibility planes (Figures 18 to 24). If the DO index would remain near 0, treatment plants would continue to be upgraded, and augmentation abstracted for irrigation. Such a direction is compatible with the official plan since wastewaters are treated to protect other legitimate river uses. The environment, quantified by DO index, would not be degraded.

Economic Policies

The last section indicated that, given near-secondary wastewater treatment, a \$25 to \$45 million per year pollution control cost range existed among feasible pollution control strategies. The actual strategy evolved by 1973, annually cost \$33 million ((D, 186) in Table 13 or Figure 19). Is this expense reasonably consistent with the Basin's economic goals?

Approximately \$12 million of the Basin's annual pollution control expenses were incurred industrially (Treatment Level D in Appendix H). The larger portion of these costs are born by the pulp and paper industry. If the entire

$12 million annually for water quality control were divided by the Basin's forest product payroll of $500 million, a low approximation of value added to forest goods, the forest industry appears to spend about 2 percent of its value added for Willamette quality protection. The Basin's agriculture, the other regional economic mainstay, spends much less.

The Basin's aesthetic environment supports substantial sporting economic activity and draws smaller industries to the region. Regional economic advancement brought on by this spinoff probably outweighs a $12 million annual environmental burden placed on the resource industries.

If the annual cost of water quality control were divided among the Basin's residents, a per capita charge of $20 would result. This corresponds to somewhat less than one-half of one percent of mean personal income. Because both reservoirs and wastewater treatment plants are federally subsidized, the direct per capita price is even smaller. Given the environmental enhancement, most Oregonians do not think that the price is excessive.

Of the $33 million annual water pollution control cost, slightly over $6 million is spent annually for fixed or independent pollution control tactics, those activities of wastewater treatment wherein the discharge quality is not reflected in the river. The remaining $27 million is the fund distributed to incremental quality-achieving alternatives. Of this, $3 million, if cost allocated, is used for reservoirs and $12 million each are spent by municipalities and industries. In that these charges are well distributed over the Basin, this spending reflects the State policy of balanced development.

The Basin's economic growth might be curtailed if industries were forced to assume a larger part of the total cost. Economic activity might be accelerated if subsidized pollution control from reservoirs and municipal plants were used to alleviate the industrial burden.

The 1973 level of augmentation and wastewater treatment is reasonably consistent with the State economic policy, its emphasis on orderly, planned and balanced growth. Significantly, however, a DO target upgraded 1 mg/l over that of 1973 could double pollution control costs and potentially disrupt economic development.

Energy Policies

If the direct energy used for pollution control (510 TJ, Table 16) is compared to Basin energy use for 1973 (350,000 TJ, Figure 13, population 1,500,000), between 0.1 and 0.2 percent of the Basin's power was consumed for water quality management. This value is in agreement with national estimates of 0.1 to 0.3 percent for electricity and petroleum required for water pollution control (83). That energy requirement could double with advances in treatment level (700 or 800 TJ for Level G, 1600 for Level H, Figure 24).

If the State's energy budget were to continuously increase at several percent per year, the energy needs for pollution control could probably be satisfactorily absorbed. This indeed reflects State and energy industry forecasts. Oregon may, however, find its energy sources curtailed sooner than anticipated. As this occurs, energy expenditures for pollution control will be more and more determined by the alternative uses in which that power might be used.

Oregon's energy policies call for diverse, permanently sustainable energy resources, conservatively used to meet basic human needs and preserve environmental quality. A logical consequence of an energy policy utilizing renewable energies would be environmental strategies drawing upon the assimilative capacity of nature. For Willamette DO maintenance, joules spent for reservoirs generally accomplish more than do joules spent in wastewater treatment, shown by an expansion path across the top of Figure 24(a). If augmentation were maximized and raw waste production fixed, pollution control activity might reduce 10 or 20 percent from its energy needs with negligible DO effects.

The energy perspective affords checks on pollution control tactics. One such check is carried out in Appendix I. The energy required to build and operate a reservoir is compared with the energy hydraulically produced. It appears that if power is generated, a 17:1 return is realized on energy invested. A similar calculation using generalized national figures indicated the ratio might be 100:1 (84). By either accounting, hydroelectric generation appears to be net energy productive, thus in conformity to policy objectives.

An Alternative Perspective

As illustrated in Section V, energy flows into and within a system provide a basis for understanding the nature of that system. The 1973 costs for Willamette pollution control were approximately $33 million, 510 direct TJ, and 1373 primary TJ (Tables 13, 15 and 17). If these dollars are translated to calorie equivalent at $1 equal to 25,000 Calories as suggested by Odum, these three measures of dollars, direct energy and primary energy are 0.83×10^{12}, 0.12×10^{12} and 0.33×10^{12} Cal/yr (51). Since the primary figure includes energy directly sold to pollution control, the difference, 0.21×10^{12} Cal/yr, represents the fossil energy consumed elsewhere and embodied in pollution control inputs. The primary energy total subtracted from the dollar energy total, 0.50×10^{12} Cal/yr, represents energy consumed in the Basin's household sector.

In Figure 14, the 0.12×10^{12} direct Cal/yr is a portion of the 87×10^{12} Cal/yr, the Basin's direct energy input. Of the 34×10^{12} Cal of imports and 45×10^{12} Cal of intraindustrial consumption, 0.21×10^{12} Cal were required for pollution control. Of the 118×10^{12} Cal ultimately consumed by the Basin's population, 0.50×10^{12} Cal were derived from water quality management.

Whereas the largest portion of water quality regulation energy is eventually consumed in the Basin's households (0.50×10^{12} of 0.83×10^{12} Cal/yr), this energy is largely an economic flow that would likely continue with or without pollution control investment. If the Valley opted for a very low quality river, the dollars would have been spent for something else. The environmental planner may be able to save the public money, but he cannot halt the spending of these savings for other goals.

The use of 0.12×10^{12} direct and 0.21×10^{12} embodied Cal/yr associated with water quality control is reasonably responsive to planning. If spent, this energy results in an overall environmental gain. If not spent, this energy might be removed from Basin imports. This last alternative is perhaps the most significant to the Basin's overall planning. The Willamette Basin is currently subsidized with imported primary energy. As the world's energy stocks dwindle, this subsidy cannot be maintained. Cutbacks in direct energy imports will occur, and energy intensive goods will be harder to obtain. Energy in both forms will be sought with increased vigor by all segments of the economy, only one of which is pollution control. It is most improbable that pollution control can garner enough energy inflows to continuously upgrade water quality (moves to the right on Figures 20(a) and (b)). It is not guaranteed under conditions of energy shortages that water pollution control can even maintain its current energy expenditures.

This paper analytically deals in the short range. A broader integrated perspective shows the differences inherent between short and long run answers. Short run policy and analysis needs to be first internally reconciled. Treatment plant investment should be coordinated with reservoir operation. Then, as understanding of the total system increases, short run perspective might as a whole be better directed toward long run solutions.

SUMMARY

This report deals with alternatives not radically different from pollution control management of 1973. The environmental, economic, and energy models selected are suitable for that base period. Even with such specification, the economic and energy expressions yield only approximations of impact. The established level of low flow augmentation appears to be of reasonable economic efficiency, given uncertainty about the value of water and demands in the future. If DO were upgraded to yet higher levels, or if energy efficiency were considered, reason would exist for selecting an environmental strategy weighted toward additional flow maintenance.

The water quality strategy of 1973 is harmonious with the substance of State environmental and economic policies. The reliance on imported energy to accomplish such regulation is not in keeping with Oregon's energy policy. It appears that the three policy perspectives have yet to be reconciled.

From a broader viewpoint, the 1973 mode of water quality control is at odds with the Basin's long range energy-based outlook. If the imported energy subsidy to Oregon's economy should dwindle, energy-cheap strategies for environmental management, such as low flow augmentation, may have to be implemented and energy-intensive alternatives reduced.

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GLOSSARY

af - Acre-ft, 1233 m^3
BOD - Biochemical Oxygen Demand
BOD_5 - Biochemical Oxygen Demand, 5 day
Btu - British thermal unit, 1055 J
C - Celsius
Cal - Calorie, 4187 J
CBOD - Carbonaceous BOD
cfs - cubic ft per second, 0.0283 m^3/s
COD - Chemical Oxygen Demand
DO - Dissolved Oxygen
ft - Feet, 0.3048 m
G - Giga, 10^9
g - Gram
J - Joule
k - Kilo, 10^3
l - Liter
m - Meter
M - Mega, 10^6
mgd - Million gallons per day, 0.04381 m^3/s
mg/l - Milligrams per liter
NBOD - Nitrogenous BOD
Rkm - River kilometer
s - Second
T - Tera, 10^{12}
Wh - Watt-hour, 3600 J

TABLE A-18. MUNICIPAL WASTEWATER TREATMENT PLANTS DISCHARGING TO WILLAMETTE, AUGUST 1973 (3, 9, 10)

Plant	Type*	Year built	Discharge, mgd		Receiving stream river kilometer
			1973	Design	
Albany	AS	1969	5.33	8.70	Willamette - 191.5
Aloha	ASEF	1965	1.20	4.00	Beaverton Cr. - 5.3
Banks	ASP	1967	.05	.14	W.Fk. Dairy Cr. - 16.1
Beaverton	TFEF	1970	1.90	1.60	Beaverton Cr. - 12.9
Canby	AS	1963	.34	.85	Willamette - 53.1
Carlton	TF	1955	.12	.30	N.Yamhill - 9.7
Cedar Hills	TF	1962	.92	1.30	Beaverton Cr. - 12.1
Central Linn Hi. School	ASP	1958	.01	.01	Spoon Cr. - 7.1
Century Meadows	ASP	1972	.04	.04	Willamette - 67.6
Chatnicka Heights	ASP	1964	.01	.04	Winslow Cr. - 7.2
Cornelius	TF	1959	.21	.25	Tualatin - 84.2
Corvallis	TF	1966	6.60	7.26	Willamette - 210.8
Corvallis Airport	L	1962	.01	.01	Cr. to Willamette - 222.0
Corvallis Mobile Home	ASP	1959	.02	.01	Oak Cr. - 2.6
Cottage Grove	TF	1967	.92	1.50	Coast Fork Willamette - 35.4
Country Squire	ASPL	1964	.02	.07	Muddy Cr. - 77.2
Creswell	L	1962	.12	.17	Camas Sw. - 8.0
Dallas	AS	1969	.70	2.00	Rickreall Cr. - 16.9
Dammasch Hospital	TF	1960	.11	.30	Corral Cr. - 1.6
Dayton	L	1965	.10	.10	Yamhill - 8.0
Dundee	L	1970	.06	.13	Willamette - 83.7
Eola Village	TF	1941	.08	.07	S.Yamhill - 24.1
Estacada	TF	1963	.12	.38	Clackamas - 38.0
Eugene	TF	1971	13.80	16.00	Willamette - 286.4
Fanno	AS	1969	3.15	3.00	Fanno Cr. - 13.4
Fir Cove Sanitation	ASP	1957	.00	.02	Coast Fork Willamette - 1.6
Gaston	ASP	1964	.04	.06	Tualatin - 103.8
Halsey	L	1969	.05	.10	Muddy Cr. - 37.0
Happy Valley Homes	ASP		.01	.01	Mitchell Cr. - 2.4
Harrisburg	TF	1967	.09	.25	Willamette - 259.0
Hillsboro	AS	1959	.91	1.25	Rock Creek - 0.0
Hillsboro Jr. Hi.	ASP	1963	.01	.01	Beaverton Cr. - 0.0
Hillsboro West	AS	1971	.86	2.00	Tualatin - 59.5
Hubbard	TF	1968	.10	.20	Mill Cr. - 8.5
Independence	L	1967	.30	.39	Ash Cr. - 2.1
Jefferson	L	1969	.10	.11	Santiam - 11.3
Lafayette	L	1964	.08	.10	Yamhill - 12.9
Laurelwood Academy	TF	1967	.04	.02	Hill Cr. - 9.7
Lebanon	TF	1958	.68	1.90	S. Santiam - 28.0
Lowell	TF	1949	.56	.26	Mid Fork Willamette - 29.8
Lowell Park	ASP	1960	.01	.01	Mid Fork Willamette - 27.2
Marylhurst	TF	1962	.62	.11	Willamette - 35.2
McMinnville	AS	1971	1.87	4.00	S. Fork Yamhill - 6.4
Metzger	AS	1966	1.50	2.50	Fanno Cr. - 7.9
Millersburg School	L	1966	.01	.01	Crooks Cr. - 10.0
Milwaukie	AS	1962	1.70	2.00	Willamette - 29.0
Molalla	TF	1955	.20	.40	Bear Cr. - 0.8
Monmouth	L	1964	.50	.70	Ash Cr. - 4.2

TABLE A-18 (continued)

Plant	Type*	Year built	Discharge, mgd		Receiving stream river kilometer
			1973	Design	
Monroe	L	1968	.04	.05	Long Tom - 10.5
Mt. Angel	TF	1955	.15	.36	Pudding - 55.8
Newberg	AS	1971	.60	2.00	Willamette - 80.9
Oak Hills	ASPL	1965	.18	.20	Willow Cr. - 4.3
Oaklodge	AS	1969	1.70	4.00	Willamette - 32.3
Oakridge	AS	1969	.44	.42	Mid Fork Willamette - 64.0
Oregon City	AS	1964	2.48	3.00	Willamette - 40.5
Philomath	AS	1952	.17	.35	Mary's R. - 18.5
Pleasant Valley Sch.	ASP	1963	.01	.01	Mitchell Cr.
Primate Center	ASP	1964	.05	.06	Bronson Cr. - 1.6
Ramada Inn	ASPL	1965	.03	.02	Tualatin - 12.9
River Vil. Trailer Park	ASP	1968	.00	.01	Willamette - 64.4
Riverview Heights	ASP	1960	.02	.05	Willamette - 185.0
Salem Willow Lake	TF	1964	23.70	17.50	Willamette - 125.8
Sandy	AS	1972	.13	.50	Trickle Cr. - 2.1
Scio	L	1963	.04	.06	Thomas Cr. - 12.9
Sherwood	TF	1965	.33	.57	Cedar Cr. - 1.3
Silverton	TF	1970	.43	.70	Silver Cr. - 5.6
Sommerset West	ASPL	1964	.39	.32	Beaverton Cr. - 12.1
Southwood Park	TF	1962	.08	.10	Ball Cr. - 1.9
Springfield	TF	1962	5.70	6.90	Willamette - 296.5
Stayton	ASEF	1964	.34	1.35	N. Santiam - 24.1
Sunset	AS	1965	1.10	1.50	Cedar Mill Cr - 4.8
Sweet Home	ASEF	1966	.40	.50	S. Santiam - 54.1
Tigard	AS	1970	.92	1.50	Fanno Cr. - 6.0
Tualatin	ASEF	1970	.16	.28	Tualatin - 13.8
Tual.Valley Develop.Co.	ASP	1965	.28	.20	Tualatin - 17.7
Twin Oaks School	TF	1958	.00	.01	Spencer Cr. - 7.7
Tyron	AS	1965	3.85	5.00	Willamette - 32.7
Westfir	ASP	1966	.03	.03	Mid Fork Willamette - 59.5
West Hills S.D.	ASP	1961	.02	.03	Oak Cr. - 2.1
West Linn Bolton	TF	1963	.44	1.30	Willamette - 38.8
West Linn Willamette	TF	1963	.20	.38	Willamette - 45.1
West Mod. Homes	ASP		.05	.05	Mill Cr. - 8.1
West Salem	AS	1969	.05	.40	Willamette - 128.7
Willow Is. Mobile Home	ASP	1973	.03	.03	Willamette
Wilsonville	ASP	1972	.15	.50	Willamette - 62.8
Woodburn	TF	1964	.60	.96	Pudding - 13.7
Yamhill	ASP	1964	.05	.10	Yamhill Cr. - 1.4

*TFEF = Trickling Filter with Effluent Filtration; ASEF = Activated Sludge with Effluent Filtration; ASP = Activated Sludge Package Plant; AS = Activated Sludge; TF = Trickling Filter; L = Lagoon; P= Primary; ASPL = Activated Sludge Package Plant with Lagoon.

TABLE A-19. MAJOR OPERATING INDUSTRIAL WASTEWATER TREATMENT PLANTS (3, 9, 10)

Plant and location	Type of process	Receiving stream river kilometer	Allowable summer discharges, kg/day	
			BOD_5/suspended solids	Other*
American Can, Halsey	Bleached Kraft pulping and tissue wastes	Willamette - 238.8	1,100/3,200	None
Boise Cascade, Salem	Bleached sulfite pulping and fine paper wastes	Willamette - 135.5	3,600/3,200	None
Crown Zellerbach, Lebanon	Sulfite pulping and linerboard wastes	S. Santiam - 26.5	1,400/1,800	None
Crown Zellerbach, West Linn	Bleached groundwood pulping and fine paper wastes	Willamette - 42.5	1,800/3,600	None
Evans Products, Corvallis	Wet process hardboard wastes; battery separator plant wastes	Willamette - 212.7	900/1,600	None
General Foods - Birds Eye, Woodburn	Fruit and vegetable processing wastes	Pudding - 43.4	110/110	None
Oregon Metallurgical, Albany	Titanium processing wastes	Oak Creek to Willamette - 192.6	0/70	Chlorides - 4,500 Fluorides - 9,000
Pennwalt, Portland	Contaminated cooling water from chlor-alkali process	Willamette - 11.9	0/0	Chlorine - 45 Chromium - 45 Ammonia - 70
Publishers Paper, Newberg	Bleached sulfite, unbleached groundwood pulping, and papermill wastes	Willamette - 80.4	2,700/3,400	None
Publishers Paper, Oregon City	Bleached sulfite and bleached groundwood pulping wastes	Willamette - 44.2	3,600/3,400	None

TABLE A-19 (continued).

Plant and location	Type of process	Receiving stream river kilometer	Allowable summer discharges, kg/day	
			BOD_5 suspended solids	Other*
Rhodia, Portland	Process waste from insecticide production	Willamette - 11.3	0/120	COD - 680 Dissolved solids - 21,000
Tektronix, Beaverton	Electroplating wastes	Beaverton Cr - 10.8 to Rock Cr to Tualatin - 61.9	0/110	Ammonium ion - 4.5
Wah Chang, Albany	Process waste from exotic metals production	Truax Cr - 3.2 to Willamette - 185.8	0/320	COD - 450 Dissolved solids - 22,000 Ammonium ion - 1,400
Western Kraft, Albany	Unbleached Kraft, neutral sulfite semi-chemical pulping and linerboard wastes	Willamette - 187.4	1,100/2,300	None
Weyerhaeuser, Springfield	Unbleached Kraft pulping and linerboard wastes	McKenzie - 23.7	1,400/4,500	None

* Inorganic waste streams have many other components.

APPENDIX B

DISCUSSION

The following discussion traces the computer modeling from data file creation to final simulated output. Figure B-25 illustrates in a schematic manner the data handling. Example data files and FORTRAN listings or routines follow in this appendix.

Total Loading (TL) Files

For each strategy of Valley pollution control, a stream-ordered listing of all known dischargers was created as a total loading (TL) data file. The example file TL1973 listed described the Willamette River dischargers of August 1973. Indentation signifies to what stream each discharge flows and to what stream each tributary discharges. British, rather than SI units, are used, conforming with raw data. River mile distance and stream velocity estimation allow calculation of travel time to the Willamette main stem for each up-tributary discharge. Tributary velocity is estimated from channel slope, summer discharge, and proximity to streams where velocities have been gaged (85).

Pollutant loadings are quantified as immediate oxygen demand (IOD), collodial/dissolved carbonaceous 5-day oxygen demand (BOD), settleable solids oxygen demand (not used in this study since settled solids are considered to exert IOD), Kjeldahl nitrogen, flow discharge, and dissolved oxygen saturation. The TL file incorporates all loadings: point source, nonpoint source (as equivalent point inputs at main stem tributary mouths), benthic demands, and abstractions (diversion of flow, BOD, and N from the main stem).

WILT

The routine WILT routed all tributary BOD and N to the Willamette main stem. Reaeration was not estimated; DO of the final main stem input is included in the TL data. Historically DO sag in tributaries has not been a major porblem. It was assumed that particular tributary quality problems, say eutrophied pools, can be resolved locally rather than as a regional concern.

WILT provided an output of a main stem loading (ML) file, a listing of first-column TL inputs, with loads now encompassing residual up-tributary oxygen-demanding discharges.

WILBER

The main stem hydraulic program, WILBER, collected all inputs from the ML file, read the design flow and percent DO saturation at Salem from a discharge (Q) file, and obtained the hydraulic constants for the Salem-Portland reaches from HYCONST. Main stem flow above Salem was routed to Salem through 7 upstream reaches. DO was not modeled in the upstream Willamette where the generally steep slopes keep the waters well aerated.

For reaches above the Newberg Pool, WILBER calculated channel depth by Manning's equation. HYDCONST gave channel width, slope and roughness while Q defined discharge. In and below the Newberg Pool, depth of summer flow does not vary with discharge because of downstream flow control. Therefore WILBER is directly given channel width and depth from HYDCONST.

WILBER generated a loading file (L) that resembles the ML file with the top boundary condition now at Salem. WILBER also generated hydraulic file (H) containing the milepoint, cross-sectional area, width, and inflow for each of the 297 downstream reaches.

WILMA

The basic DO smulation routine WILMA routed flow reach by reach from Salem to Portland. Velz's rational accounting method of DO was employed. WILMA drew data from a H and L file and a user written temperature file, T. In T, temperature can be given for any of the reach nodes. Nodes with unspecified temperature assume the value of the immediately upstream node. WILMA did the following:

1) Establishes deoxygenation rate constants and Velz stream type;
2) Converts BOD_5 into CBOD ultimate;
3) Converts Kjeldahl N into NBOD;
4) Calculates average area, temperature, depth, and DO saturation for each reach;
5) Corrects rate constants for temperature;
6) Determines oxygen, CBOD, and NBOD inputs at the top of each reach;
7) Determines CBOD and NBOD satisfied in each reach;
8) Removes IOD exerted;
9) Calculates reaeration in each reach;
10) Routes outputs to the downstream reach; and
11) Generates documentation including

    - File name references,
    - Lower mainstem loading summary,
    - Temperature and saturation summary,
    - Reach by reach hydraulic conditions,
    - Reach by reach temperature-corrected rate constants,
    - Reach by reach DO balance tabulation,
    - Travel times to each reach node, and
    - DO at each reach node.

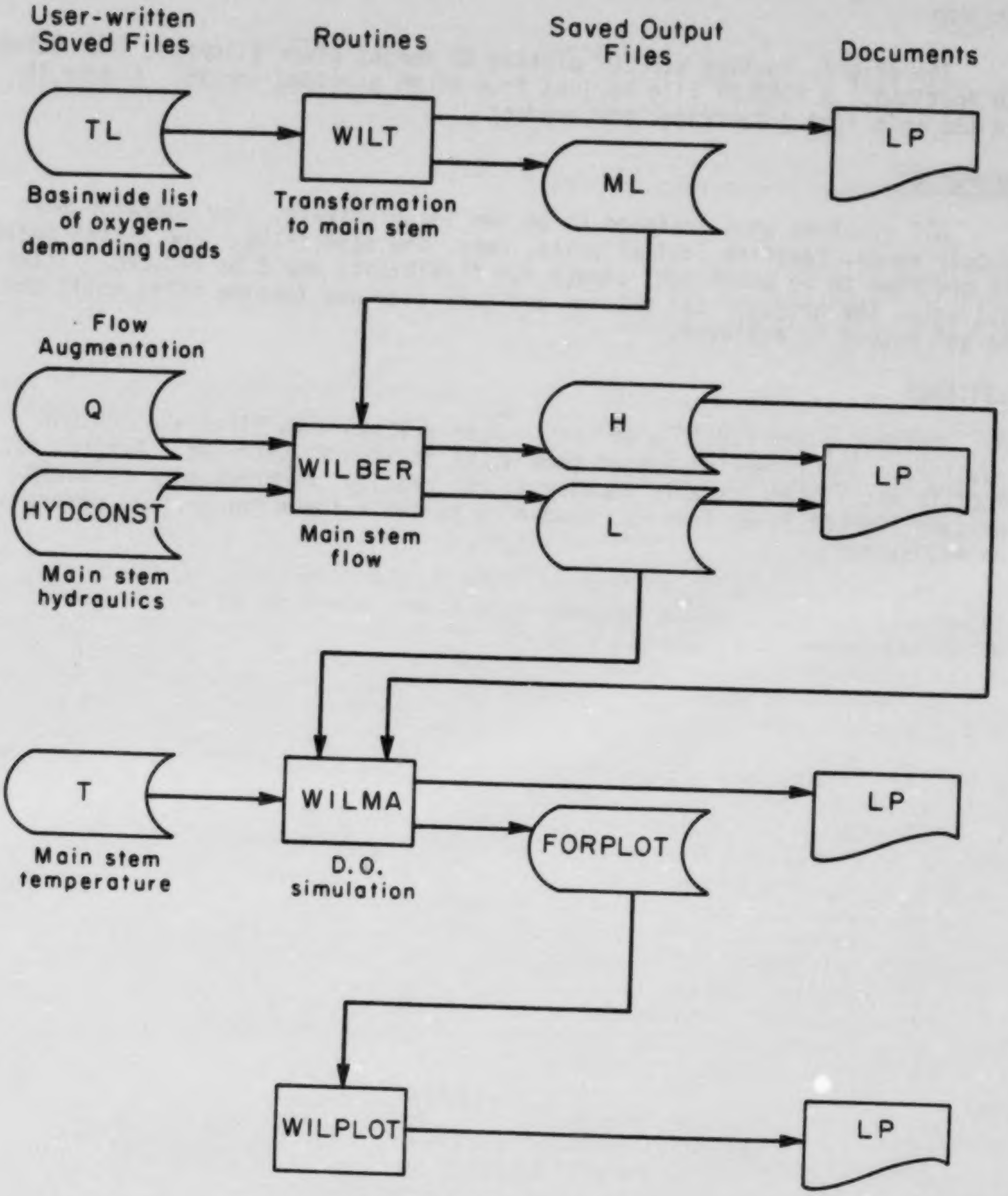
User-written Saved Files
Routines
Saved Output Files
Documents
TL
WILT
LP
ML
Basinwide list of oxygen-demanding loads
Transformation to main stem
Flow Augmentation
Q
HYDCONST
Main stem hydraulics
WILBER
Main stem flow
H
L
LP
T
Main stem temperature
WILMA
D.O. simulation
FORPLOT
LP
WILPLOT
LP

Figure B-25. Data handling schematic.

WILPLOT

The graphic routine WILPLOT plotted DO versus river kilometer from Salem to Portland. A FORPLOT file derived from WILMA provided inputs. Figure 16 in the main text illustrates the product.

Operation

All routines were designed to be run interactively. The operator must supply names, redefine logical units, copy, and save files. The system could be modified to be batch run, though run flexibility would be reduced. Interactively, the operator can recover and vary flow and loading files until the target output is achieved.

LISTINGS

Following are listings of sample user-written data files and FORTRAN routines. The lineprint output from WILMA is also illustrated. Program WILPLOT is not listed, as this routine is not readily transportable. A WILMA-written FORPLOT file, however, should be suitable input for graphic programs on any system.

TABLE B-20. LISTING OF COMPUTER FILES

TL File

```
TL1973
BENTHIC DEMAND                5.20            6000.
BENTHIC DEMAND                6.20            6000.
RHODIA                        7.00                      1500.                   .20       .75
PENNWALT                      7.20                                  150.        57.23     .75
BENTHIC DEMAND                9.23            6000.
BENTHIC DEMAND                9.20            6000.
BENTHIC DEMAND                12.84           6000.
MILWAUKIE                     13.39                     200.        284.        2.63      .5
JOHNSON CREEK                 18.40   2.                                        1.        .8
 NPS                                                    12.         18.
 MITCHELL CREEK               11.00   3.
  HAPPY VALLEY HOMES          1.30                      1.5         1.          .01       .5
  PLEASANT VALLEY SCH         1.30                      1.          1.          .01       .5
OAKLODGE                      19.90                     525.        284.        2.63      .5
TYRON                         20.23                     349.        644.        5.96      .5
MARYLHURST                    21.87                     15.         83.         .96       .5
WEST LINN BOLTON              24.14                     131.        59.         .68       .5
CLACKAMAS RIVER               24.92   1.                                        853.      .96
 NPS                                                    2770.       108.
 DEER CREEK                   12.1    1.1
  TICKLE CREEK                2.9     1.2
   SANDY                      1.3                       22.         22.         .20       .5
 ESTACADA                     23.6                      10.         16.         .19       .5
OREGON CITY                   25.21                     320.        415.        3.84      .5
PUBLISHERS PAPER              27.60                     8000.                   20.88     .5
WEST LINN WILLAMETTE          27.80                     35.         27.         .31       .5
CROWN ZELLERBACH              28.00                     4000.                   22.89     .5
TUALATIN RIVER                28.45   .2                                        36.       .9
 NPS                                                    1643.       0.
 RAMADA INN                   8.0                       7.                      .04       .5
 TUALATIN                     8.6                       20.         16.         .25       .5
 FANNO CREEK                  9.4     .3
  BALL CREEK                  2.0     .3
   SOUTHWOOD PARK             1.2                       13.         10.         .12       .5
  TIGARD                      3.7                       80.         154.        1.42      .5
  METZGER                     4.9                       250.        241.        2.32      .5
  FANNO                       8.3                       500.        526.        4.87      .5
 TUAL VALLEY DEVELOP CO       11.0                      50.         46.         .43       .5
 CHICKEN CREEK                15.6    .3
  CEDAR CREEK                 1.5     .4
   SHERWOOD                   1.1                       80.         44.         .51       .5
 ROCK CREEK                   38.1    .3
  HILLSBORO                   0.1                       160.        152.        1.41      .5
  BEAVERTON CREEK             4.3     .4
   HILLSBORO JR HI            0.0                       2.          2.          .02       .5
   BRONSON CREEK              1.0     .4
    PRIMATE CENTER            1.0                       8.          9.          .08       .5
   ALOHA                      3.3                       100.        121.        1.86      .5
   WILLOW CREEK               6.5     .4
    OAK HILLS                 2.7                       32.                     .28       .5
   CEDAR MILL CREEK           7.0     .4
    SUNSET                    3.0                       190.        184.        1.70      .5
    TEKTRONIX                 7.0                       60.         540.        .93       .5
    BEAVERTON                 8.0                       300.        191.        2.94      .5
    CEDAR HILLS               9.0                       125.        123.        1.42      .5
  SOMMERSET WEST              7.5                       50.                     .60       .5
 HILLSBORO WEST               39.0                      335.        145.        1.34      .5
 DAIRY CREEK                  44.5    .2
  WEST FORK DAIRY             10.0    .3
   BANKS                      10.0                      8.          8.          .07       .5
 CORNELIUS                    52.3                      20.         28.         .32       .5
 HILL CREEK                   62.0    .4
  LAURELWOOD ACADEMY          6.0                       7.          5.          .06       .5
 GASTON                       64.5                      12.         6.          .06       .5
WILLOW IS MOBILE HOME         31.6                      5.          6.          .05       .5
CANBY                         33.0                      71.         57.         .53       .5
MOLALLA RIVER                 35.75   .4                                        77.       1.
 NPS                                                    180.        154.
 PUDDING RIVER                0.8     .2
  MILL CREEK                  7.2     .3
   WEST MOO HOMES             5.0                       8.5         9.          .08       .5
   HUBBARD                    5.3                       18.         13.         .15       .5
   WOODBURN                   9.5                       200.        80.         .93       .5
  ROCK CREEK                  15.5    .3
   BEAR CREEK                 0.5     .4
    MOLALLA                   10.0                      60.         27.         .31       .5
  BIRDSEYE                    27.                       250.                    1.50      .5
  MT ANGEL                    34.7                      50.         20.         .23       .5
  SILVER CREEK                42.2    .3
   SILVERTON                  3.5                       80.         58.         .67       .5
```

TABLE B-20 (continued).

WILSONVILLE	39.0		20.	57.	.23	.5
DAMMASCH HOSPITAL	39.8		20.	15.	.17	.5
ABSTRACTION	40.0		-255.	-74.	-70.	.85
RIVER VIL TRAILER PARK	40.2		1.	1.	.01	.5
CENTURY MEADOWS	42.		10.	6.	.06	.5
PUBLISHERS PAPER	49.9		6000.		14.23	.5
ABSTRACTION	50.0		-259.	-68.	-70.	.85
NEWBERG	50.5		115.	101.	.93	.5
DUNDEE	51.8		15.		.09	.5
YAMHILL	55.0	.3			37.	.9
NPS			285.	0.		
DAYTON	5.3		26.		.15	.5
LAFAYETTE	8.0		22.		.13	.5
NORTH FORK YAMHILL	11.2	.4				
CARLTON	6.0		25.	16.	.19	.5
YAMHILL CREEK	13.2	.4				
YAMHILL	0.9		11.	9.	.08	.5
SOUTH FORK YAMHILL	11.2	.4				
MCMINNVILLE	4.0		203.	322.	2.89	.5
EOLA VILLAGE	15.0		13.	10.	.12	.5
ABSTRACTION	60.0		-329.	-89.	-70.	.85
ABSTRACTION	70.0		-398.	-176.	-70.	.85
SALEM WILLOW LAKE	77.9		10000.	3000.	33.66	.1
GLEN CREEK	79.0	.5			0.	0.
WINSLOW CREEK	2.0	.5				
CHATNICKA HEIGHTS	4.5		2.	2.	.02	.5
WEST SALEM	80.		10.	8.	.07	.5
ABSTRACTION	81.0		-254.	-204.	-70.	.90
MILL CREEK	84.0	.5			46.	.9
BOISE CASCADE	85.0		10000.	20000.	19.49	.5
RICKREALL CREEK	88.1	.4			4.	.9
NPS			16.	0.		
DALLAS	10.5		47.	108.	1.08	.5
ASH CREEK	95.3	.5			1.2	.8
NPS			0.	2.		
INDEPENDENCE	1.3		70.		1.23	.5
MONMOUTH	2.6		131.		.77	.5
ABSTRACTION	100.		-42.	-38.	-13.	.90
LUCKIAMUTE RIVER	107.5	.5			15.	.9
NPS			202.	14.		
SANTIAM RIVER	109.0	1.6			1702.	.9
NPS			7272.	779.		
COOKS CREEK	3.0	.9				
MILLERSBURG SCHOOL	5.2		2.		.02	.5
JEFFERSON	7.0		26.		.15	.5
NORTH SANTIAM	11.7	2.6				
STAYTON	15.0		60.	34.	.53	.5
SOUTH SANTIAM	11.7	1.3				
THOMAS CREEK	2.0	1.2				
SCIO	9.0		11.0		.06	.5
CROWN ZELLERBACH	16.5		3000.		7.13	.5
LEBANON	17.4		177.	91.	1.05	.5
SWEET HOME	33.6		100.	40.	.62	.5
RIVERVIEW HEIGHTS	115.0		3.	2.	.02	.5
WESTERN KRAFT	116.5		2500.		10.21	.5
WAH CHANG	117.0		1000.	2000.	3.09	.5
UNIDENTIFIED	117.0			13000.	0.	0.
ALBANY	119.0		1112.	892.	8.25	.5
OREGON METALLURGICAL	119.0				1.85	.5
CALAPOOIA RIVER	119.5	.3			24.	.9
NPS			310.	40.		
CENTRAL LINN HI SCHOOL	22.1		2.	2.	.02	.5
ABSTRACTION	120.		-39.	-3.	-13.	.90
CORVALLIS	131.0		2780.	893.	10.21	.5
MARYS RIVER	132.1	.3			11.	.9
NPS			120.	0.		
OAK CREEK	1.1	.6				
WEST HILLS S D	1.3		2.	2.	.02	.5
CORVALLIS MOBILE HOME	1.6		5.	3.	.03	.5
PHILOMATH	11.5		29.	28.	.26	.5
EVANS PRODUCTS	132.2		2000.		2.66	.5
MUDDY CREEK	132.6	.2			0.	0.
NPS			0.	0.		
HALSEY	23.0		13.		.08	.5
COUNTRY SQUIRE	48.0		3.		.03	.5
CORVALLIS AIRPORT	138.0		2.		.02	.5
ABSTRACTION	140.		-32.	-3.	-13.	.90
LONG TOM RIVER	145.9	.4			37.	.9
NPS			490.	59.		
MONROE	6.5		11.		.07	.5
COYOTE CREEK	30.2	.4				
TWIN OAKS SCHOOL	4.8		1.	1.	.01	.5
AMERICAN CAN	149.4		2500.		26.25	.5
ABSTRACTION	160.		-41.	-3.	-13.	.9

TABLE B-20 (continued).

```
HARRISBURG                    161.0           32.          11.     .13     .5
ABSTRACTION                   170.            -121.        -6.     -45.    .98
MCKENZIE                      171.8   2.6                          2334.   1.
  NPS                                         10397.       455.
  WEYERHAUSER                 14.7            3000.                25.37   .5
EUGENE                        178.0           5300.        1846.   21.35   .5
ABSTRACTION                   180.            -110.        -6.     -45.    .98
SPRINGFIELD                   184.3           1612.        763.    8.82    .5
MIDDLE FORK                   187.0   3.2                          2210.   .9
  NPS                                         12448.       401.
  LOWELL PARK                 16.9            2.           1.      .01     .5
  LOWELL                      18.5            14.          75.     .87     .5
  WESTFIR                     37.0            8.           5.      .05     .5
  OAKRIDGE                    39.8            80.          74.     .68     .5
COAST FORK                    187.0   .7                           241.    .9
  NPS                                         1034.        49.
  FIR COVE SANITATION         1.0             2.           1.      .01     .5
  CAMAS SLOUGH                10.0    1.
   CRESWELL                   5.0             30.                  .19     .5
  COTTAGE GROVE               22.             400.         123.    1.42    .5
```

T File

```
T20
   86.50      20.00
   53.40      20.20
   53.20      20.40
   53.00      20.60
   52.80      20.80
   52.60      21.00
   45.85      21.20
   45.60      21.40
   45.40      21.60
   45.20      21.80
   45.00      22.00
   37.80      22.20
   37.60      22.40
   37.40      22.60
   37.20      22.80
   37.00      23.00
   26.37      23.10
   26.20      23.20
   25.00      23.30
   25.74      23.40
   25.56      23.50
```

Q File

```
6560.     .85
```

TABLE B-20 (continued)

HYDCONST File

```
86.50   455  .000281   .02661
85.90   295  .000281   .03557
85.20   370  .000281   .03033
85.00   409  .000281   .02779
84.00   545  .000287   .02303
83.90   415  .000287   .01248
83.00   516  .000287   .01082
82.00   531  .000287   .01062
81.00   460  .000287   .01167
80.00   375  .000287   .01332
79.90   245  .000282   .01725
77.90   290  .000282   .01545
77.90   400  .000282   .02155
77.00   295  .000282   .02607
76.00   390  .000282   .02227
75.00   400  .000492   .02947
74.00   360  .000492   .03943
73.00   360  .000492   .03043
72.00   445  .000492   .02659
71.90   355  .000492   .02922
71.00   390  .000514   .02961
70.00   270  .000514   .03594
69.00   260  .000514   .03675
68.00   300  .000514   .03771
67.00   370  .000291   .02226
66.90   325  .000291   .02414
65.00   375  .000291   .02207
64.90   335  .000291   .03499
64.90   295  .000291   .03779
63.00   390  .000287   .03216
62.00   360  .000287   .03326
61.00   350  .000287   .03383
60.20   260  .000287   .04042
60.00   285  .000287   .01220
59.00   365  .000260   .00991
58.00   210  .000260   .01401
57.00   210  .000260   .01401
56.00   210  .000260   .01401
55.20   210      5.95
55.00   367      9.06
54.90   337      5.65
54.60   510      4.56
54.45   650      7.15
54.20   470     11.97
54.00   570     19.82
53.90   619      7.80
53.60   774      5.91
53.40   640      5.45
53.20   610      5.41
53.00   467     12.85
52.90   505     10.30
52.60   600     23.46
52.40   439     19.77
52.20   720      8.97
52.05   790      7.43
51.90   710     11.90
51.60   710     10.56
51.40   770     11.05
51.00   910     12.59
50.90   950     15.86
50.65   695     12.44
50.50   690     11.43
50.40   700     17.45
50.20   650     21.24
50.00   470     21.17
49.90   520     22.40
49.60   520     24.99
49.40   520     20.83
49.20   490     21.56
49.00   600     22.94
48.90   580     25.05
48.60   440     24.74
48.40   520     19.36
48.20   570     17.05
48.00   597     15.72
47.75   638     15.40
47.60   620     16.27
47.40   680     15.90
47.20   590     23.12
47.00   550     22.67
46.90   489     23.94
46.55   570     24.09
46.40   600     25.65
46.20   650     21.36
46.00   650     29.50
```

```
45.85   600   22.39
45.60   647   23.67
45.40   665   26.62
45.20   725   23.21
45.00   749   17.89
44.75   820   19.62
44.55   570   27.75
44.40   580   27.92
44.20   657   26.74
44.05   590   20.00
43.90   670   20.83
43.60   680   20.33
43.40   659   26.86
43.20   580   29.09
43.00   566   21.62
42.90   649   25.39
42.60   694   23.20
42.40   584   26.20
42.20   550   29.90
42.00   635   28.52
41.90   616   27.68
41.60   530   27.65
41.40   565   21.39
41.20   600   24.51
41.00   695   22.71
40.90   650   20.36
40.40   620   29.11
40.60   600   29.12
40.20   620   23.45
40.00   640   21.27
39.90   565   20.16
39.60   600   25.71
39.40   617   27.45
39.25   636   20.59
39.00   685   22.29
38.75   950   21.45
38.60   600   21.03
38.40   650   29.73
38.20   650   21.32
38.00   570   20.03
37.90   650   27.62
37.60   650   27.67
37.40   700   25.01
37.20   690   29.01
37.00   650   22.73
36.90   650   21.16
36.60   612   26.85
36.40   659   25.29
36.20   710   22.00
36.00   620   23.06
35.75   600   24.61
35.60   570   19.42
35.45   701   23.40
35.20   620   22.37
35.00   620   21.78
34.90   630   21.56
34.60   750   22.13
34.40   780   27.39
34.26   580   17.05
34.20   700   26.74
34.00   860   17.66
33.90   850   29.09
33.60   600   23.71
33.10   789    9.74
33.05  1310   17.65
33.00   960   17.23
32.90   840   16.76
32.60   750   16.72
32.45   920   23.40
32.40   800   22.16
32.25   730   23.75
32.05   970    7.06
31.90   920   12.13
31.60   910   17.64
31.42   820   12.24
31.20   790   42.59
31.00   790   24.56
30.90   690   14.76
30.56  1100    9.79
30.20   420   20.97
30.00   310   26.47
29.90   570   21.04
29.60  1300   19.11
29.40  1090   23.73
29.20  1170   22.20
```

TABLE B-20 (continued)

29.00	1300	16.75
28.90	1235	16.64
28.55	1190	16.87
28.45	795	41.09
28.35	760	41.13
28.15	780	31.82
28.07	910	31.57
28.00	960	32.96
27.90	960	30.20
27.80	990	30.99
27.60	1010	30.01
27.40	910	30.01
27.20	730	26.43
27.05	1090	24.16
26.99	780	10.00
26.83	230	10.00
26.57	600	10.00
26.37	265	15.32
26.25	195	26.63
26.00	660	25.00
25.76	970	15.55
25.56	540	11.37
25.47	760	11.67
25.21	625	11.69
25.00	665	11.86
24.82	380	14.13
24.59	660	13.91
24.16	780	26.51
24.16	720	15.90
24.10	660	25.50
23.80	640	16.23
23.60	660	16.97
23.57	610	16.38
23.40	610	14.36
23.00	925	23.22
22.70	475	15.67
22.51	200	16.20
22.47	650	16.09
22.27	665	16.20
21.97	625	66.46
21.60	685	69.20
21.66	365	60.81
21.23	675	65.00
20.96	645	61.61
20.62	640	66.46
20.52	110	62.25
20.23	565	67.36
19.90	665	62.09
19.77	990	35.41
19.57	670	60.30
19.60	475	60.53
19.16	760	70.06
19.30	215	30.29
18.86	965	66.29
18.54	1110	65.51
18.50	964	67.52
18.60	964	67.52
18.70	960	67.52
18.36	785	66.18
18.17	965	35.65
18.10	815	35.06
17.92	840	66.06
17.73	950	66.31
17.56	690	65.06
17.35	960	52.07
17.16	955	51.60
17.10	1000	56.60
16.66	1231	26.66
16.54	1300	25.25
16.61	960	26.03
16.16	720	26.67
16.00	1260	26.65
15.92	1505	26.78
15.57	1770	142.90
15.39	1199	24.87
15.22	1216	27.62
15.10	1075	29.10
14.78	403	25.60
14.52	735	33.65
14.35	655	65.90
14.16	720	26.67
14.00	1569	26.89
13.92	1320	36.36
13.57	1290	38.86
13.41	1270	38.31

13.72	1600	29.78
13.00	1180	29.09
12.85	1005	37.61
12.57	920	43.10
12.46	920	45.06
12.23	1060	43.76
12.09	925	45.60
11.97	765	69.36
11.60	1000	69.46
11.40	1265	63.00
11.20	1180	61.27
11.30	1115	67.09
11.73	1165	69.66
10.60	1150	65.92
10.60	1120	65.95
10.20	1210	61.95
10.50	1710	61.33
9.80	2135	61.33
9.60	1665	36.33
9.60	1675	35.60
9.20	1670	57.62
9.00	1710	66.90
8.90	2325	65.06
8.60	2460	69.62
8.60	2250	61.21
8.23	1765	64.63
7.96	2345	52.06
7.90	2435	67.02
7.60	2555	61.21
7.40	2360	66.36
7.20	2200	62.07
7.00	1760	61.66
6.84	1355	61.82
6.60	1616	61.98
6.50	1966	61.21
6.20	1560	61.72
6.00	1600	61.67
5.80	1210	61.29
5.60	1320	61.06
5.40	1290	65.94
5.20	1360	65.94
5.00	1500	65.51

TABLE B-21. LISTING OF WILT PROGRAM

WILT

```
      PROGRAM WILT
      DIMENSION WORD(5), NORD(200), TITLE(200,3), X(200,8), TOT(200),
     $ AK1(200), AKN(200)
      READ (1,15) TNULL
      N = 0
      NMS = 0
      DO 2 I=1,200
         IF (EOF(1)) GO TO 3
         N = N+1
         READ (1,16) WORD
         DO 1 J=1,5
            IF (WORD(J).EQ.#    #) GO TO 1
            NORD(I) = J
            GO TO 2
1        CONTINUE
2     CONTINUE
3     REWIND 1
      READ (1,15) TLTIT
      READ (1,17) ((TITLE(I,J),J=1,3),(X(I,J),J=1,8),I=1,N)
      C = .04111
      DO 10 I=1,N
         GO TO (4,5,6,7,8), NORD(I)
4        VEL1 = X(I,2)
         TOT(I) = 0.
         GO TO 9
5        VEL2 = X(I,2)
         TOT2 = X(I,1)/VEL1*C
         TOT(I) = TOT2
         GO TO 9
6        VEL3 = X(I,2)
         TOT3 = TOT2+X(I,1)/VEL2*C
         TOT(I) = TOT3
         GO TO 9
7        VEL4 = X(I,2)
         TOT4 = TOT3+X(I,1)/VEL3*C
         TOT(I) = TOT4
         GO TO 9
8        VEL5 = X(I,2)
         TOT(I) = TOT4+X(I,1)/VEL4*C
9        AK1(I) = .50
         AKN(I) = .2
10    CONTINUE
      K = N
      TBOD2 = 0.
      TBODN = 0.
11    CONTINUE
      IF (NORD(K).EQ.1) GO TO 12
      TBOD2 = TBOD2+X(K,4)*10.**(-AK1(K)*TOT(K))
      TBODN = TBODN+X(K,6)*10.**(-AKN(K)*TOT(K))
      GO TO 13
12    X(K,4) = X(K,4)+TBOD2
      X(K,6) = X(K,6)+TBODN
      NMS = NMS+1
      TBOD2 = 0.
      TBODN = 0.
13    K = K-1
      IF (K.GE.1) GO TO 11
      WRITE (2,15) TLTIT
      WRITE (2,17) ((TITLE(I,J),J=1,3),(X(I,J),J=1,8),I=1,N)
      WRITE (3,19) TLTIT,NMS
      DO 14 I=1,N
         IF (NORD(I).NE.1) GO TO 14
         WRITE (3,17) (TITLE(I,J),J=1,3),(X(I,J),J=1,8)
14    CONTINUE
      CALL EXIT
C
15    FORMAT (A8)
16    FORMAT (5A1)
17    FORMAT (3A8,2F7.2,4F7.0,2F7.2)
18    FORMAT (#DATA FROM FILE #,A8//26X,#RIVER    VEL ***LBS #,#PER DAY B
     $OD***     BOD    FLOW    PCT#/# FACILITY AND LOCATION#,#     MILE
     $FPS  IMMED COL/DIS SOLID    NITR     CFS    SAT#)
19    FORMAT (#FROM FILE #,A8/I3,# INFLOWS#)
      END
```

TABLE B-22. LISTING OF WILBER PROGRAM

WILBER

```
      PROGRAM WILBER
      DIMENSION TITLE(200,3), X(200,8), RT(6), Q(7), V(7), TOT(200), YMP
     $(297), YW(297), YS(297), YN(297), YQ(297), YA(297), YQIN(297), DEP
     *(297)
      IWILMA = 0
      T9001 = 0.
      T9002 = 0.
      T9003 = 0.
      T900N = 0.
      READ (2,23) TLTIT,NMS
      READ (2,24) ((TITLE(I,J),J=1,3),(X(I,J),J=1,8),I=1,NMS)
      READ (3,25) Q841,TPCT
      Q(1) = .9936*Q841
      Q(2) = .7287*Q841
      Q(3) = .7250*Q841
      Q(4) = .7234*Q841
      Q(5) = .7208*Q841
      Q(6) = .3700*Q841
      Q(7) = .3700*Q841
      V(1) = .09957*Q(1)**0.391
      V(2) = .02590*Q(2)**0.527
      V(3) = .03252*Q(3)**0.513
      V(4) = .00602*Q(4)**0.699
      V(5) = .02290*Q(5)**0.595
      V(6) = .00615*Q(6)**0.712
      V(7) = .01860*Q(7)**0.576
      C = .06111
      RT(1) = 22.5/V(1)*C
      RT(2) = 10.5/V(2)*C+RT(1)
      RT(3) = 12.6/V(3)*C+RT(2)
      RT(4) = 13.8/V(4)*C+RT(3)
      RT(5) = 25.9/V(5)*C+RT(4)
      RT(6) = 8./V(6)*C+RT(5)
      AK1 = .04
      AKN = .2
      DO 1 I=1,NMS
         IF (X(I,1).GE.86.5) GO TO 2
    1 IWILMA = IWILMA+1
    2 ITOP = IWILMA+1
      DO 11 I=ITOP,NMS
         IF (X(I,1).LE.109.0) GO TO 3
         IF (X(I,1).LE.119.5) GO TO 4
         IF (X(I,1).LE.132.1) GO TO 5
         IF (X(I,1).LE.145.9) GO TO 6
         IF (X(I,1).LE.171.8) GO TO 7
         IF (X(I,1).LE.179.8) GO TO 8
         GO TO 9
    3    TOT(I) = (X(I,1)-86.5)/V(1)*C
         GO TO 10
    4    TOT(I) = (X(I,1)-109.0)/V(2)*C+RT(1)
         GO TO 10
    5    TOT(I) = (X(I,1)-119.5)/V(3)*C+RT(2)
         GO TO 10
    6    TOT(I) = (X(I,1)-132.1)/V(4)*C+RT(3)
         GO TO 10
    7    TOT(I) = (X(I,1)-145.9)/V(5)*C+RT(4)
         GO TO 10
    8    TOT(I) = (X(I,1)-171.8)/V(6)*C+RT(5)
         GO TO 10
    9    TOT(I) = (X(I,1)-179.8)/V(7)*C+RT(6)
   10    T9002 = T9002+X(I,4)*10.**(-AK1*TOT(I))
   11 T900N = T900N+X(I,6)*10.**(-AKN*TOT(I))
      IF (X(ITOP,1).NE.86.5) GO TO 12
      T9001 = X(ITOP,3)
      T9003 = X(ITOP,5)
   12 IUP = IWILMA
      QUP = 0.
   13 CONTINUE
      IF (X(IUP,1).LE.84.1) GO TO 14
      QUP = QUP+X(IUP,7)
      IUP = IUP-1
      GO TO 13
   14 QUP = Q841-QUP
      WRITE (5,26) T9001,T9002,T9003,T900N,TPCT
      I = IWILMA
   15 WRITE (5,27) X(I,1),(X(I,J),J=3,6),X(I,8),(TITLE(I,J),J=1,3)
      IF (I.EQ.1) GO TO 16
      I = I-1
      GO TO 15
```

TABLE B-22 (continued).

```
 16 READ (1,29)  (YMP(I),YW(I),YS(I),YN(I),I=1,38)
    READ (1,29)  (YMP(I),YW(I),DEP(I),I=39,297)
    YQ(1) = QUP
    YQIN(1) = QUP
    YQTOT = QUP
    K = IWILMA
    DO 18 I=2,297
        IF (K.LE.0) GO TO 17
        IF (X(K,1).LT.YMP(I)) GO TO 17
        YQTOT = YQTOT+X(K,7)
        K = K-1
 17     YQ(I) = YQTOT
 18 YQIN(I) = YQ(I)-YQ(I-1)
    D = 5.
    DO 20 I=1,38
        A = YN(I)*YQ(I)/(1.49*YS(I)**.5*YW(I)**1.66666)
        A = A**1.5
        IT = I
        KOUNT = 0
        STEP = .005
        SIGN = +1.
        PROP = 2.
        W = YW(I)
        RHS = D**2.5/A-2.*D
        IF(RHS.GT.W)SIGN = -1.
 19     RHSLAST = RHS
        KOUNT = KOUNT+1
        IF (KOUNT.GT.40) GO TO 22
        STEP = SIGN*PROP*STEP
        IF(STEP.LT.-D)STEP = -D
        D = D+STEP
        RHS = D**2.5/A-2.*D
        IF (ABS(RHS-W).LT..01) GO TO 20
        SIGN = +1.
        IF ((RHS-W)*(RHSLAST-W).GT.0.) GO TO 19
        SIGN = -1.
        PROP = .5
        GO TO 19
 20 YA(I) = D*YW(I)
    DO 21 I=39,297
 21 YA(I) = DEP(I)*YW(I)
    WRITE (4,30) (I,YMP(I),YA(I),YW(I),YQIN(I),I=1,297)
    CALL EXIT
 22 WRITE (61,31) IT
    CALL EXIT
C
 23 FORMAT (10X,A8/I3)
 24 FORMAT (3A8,2F7.2,4F7.0,2F7.2)
 25 FORMAT (2F10.0)
 26 FORMAT (≠ 86.50≠,4F10.0,F6.2,≠  TOP OF MODEL≠)
 27 FORMAT (F6.2,4F10.0,F6.2,2X,3A8)
 28 FORMAT (F6.2,F5.0,F8.6,F8.5)
 29 FORMAT (F6.2,F5.0,F8.2)
 30 FORMAT (I3,F6.2,F7.0,F5.0,F8.2)
 31 FORMAT (≠ ITERATION≠,I4)
    END
```

TABLE B-23. LISTING OF WILMA PROGRAM

WILMA

```
      PROGRAM WILMA
      DIMENSION X(297), A(297), W(297), T(297), D(297), V(297), AVT(297)
     $, AVA(297), AVD(297), Q(297), QIN(297), TIN(297), TTO(297), NTYPE
     $(297), AK1(297), AKZ(297), AKN(297), BOD(3,297), BCON(297), PCTIN
     $(297), DCIN(297), DOUS(297), BODIN(297), RCUS(297), RNUS(297),
     $ BODSAT(297), PCTUS(297), S(297), AVS(297), PCTOP(297), REAER(297)
     $, IRT(297), IRL(297), PPM(297), XKM(297)
C
C     SET COMMCN REACH PARAMETERS
C
      DO 1 I=1,38
         NTYPE(I) = 1
         AKZ(I) = .05
    1 AKN(I) = .4
      DO 2 I=39,185
         NTYPE(I) = 1
         AKZ(I) = .02
    2 AKN(I) = .0
      DO 3 I=186,297
         NTYPE(I) = 2
         AKZ(I) = .02
    3 AKN(I) = 0.
C
C     READ HYDRAULIC DATA
C
      READ (1,30) TITH
      READ (1,31) (X(I),A(I),W(I),QIN(I),I=1,297)
C
C     READ AND SET TEMPERATURES
C
      READ (2,30) TITT
      KT = 0
      NLAST = 0
    4 NSTART = NLAST+1
      READ (2,32) XTEST,TT
      IF (EOF(2)) GO TO 7
      DO 6 I=NSTART,297
         IF (X(I)-XTEST) 28,5,6
    5    T(I) = TT
         KT = KT+1
         IPT(KT) = I
         NLAST = I
         GO TO 4
    6 T(I) = T(I-1)
    7 CONTINUE
      IF (NLAST.EQ.297) GO TO 9
      DO 8 I=NSTART,297
    8 T(I) = T(I-1)
    9 CONTINUE
C
C     READ LOACINGS
C
      READ (3,30) TITL
      KL = 0
      NLAST = 0
   10 NSTART = NLAST+1
      READ (3,33) XTEST,B1,B2,B3,BN,PCTX
      IF (EOF(3)) GO TO 12
      DO 12 I=NSTART,297
         IF (X(I)-XTEST) 28,11,12
   11    PCTIN(I) = PCTX
         BOD(1,I) = B1
         BOD(2,I) = B2*2.004
         BOD(3,I) = B3
         BODN(I) = BN*4.3
         KL = KL+1
         IRL(KL) = I
         NLAST = I
         GO TO 10
   12 CONTINUE
C
C     EVALUATE REACH
C
      Q(1) = QIN(1)
      D(1) = A(1)/W(1)
      S(1) = 14.35278-.32276*T(1)+.0032*T(1)**2
      XKM(1) = X(1)*1.60934
      DO 19 M=1,296
         N = M+1
         Q(N) = Q(M)+QIN(N)
         D(N) = A(N)/W(N)
```

TABLE B-23 (continued).

```
      S(N) = 14.35278-.32276*T(N)+.0032*T(N)**2
      XKM(N) = X(N)*1.60934
      AVA(M) = .5*(A(M)+A(N))
      AVT(M) = .5*(T(M)+T(N))
      AVD(M) = .5*(D(M)+D(N))
      AVS(M) = 14.35279-.32276*AVT(M)+.0032*AVT(M)**2
      AK1(M) = AKZ(M)*1.047**(AVT(M)-20.)
      TIN(M) = AVA(M)*(X(M)-X(N))/(Q(M)*16.3636)
      TTO(N) = TTO(M)+TIN(M)
      V(M) = (X(M)-X(N))/TIN(M)
      GO TO (13,14), NTYPE(M)
   13 AMI = 1.79753+3.09053*AVD(M)-.08841*AVD(M)**2+.00692*AVD(M)**3
      GO TO 15
   14 AMI = 1.42624+2.21515*AVD(M)-.06136*AVD(M)**2+.00063*AVD(M)**3
   15 DOIN(M) = DOUS(M)+QIN(M)*PCTIN(M)*S(M)*5.3913
      PCTOP(M) = ((Q(M)-QIN(M))*PCTUS(M)+QIN(M)*PCTIN(M))/Q(M)
      IF(M.EQ.185)DOIN(M) = DOIN(M)+7.83*QIN(1)*(1.-PCTOP(M))
      BODIN(M) = RCUS(M)+RNUS(M)+BOD(1,M)+BOD(2,M)+BOD(3,M)+BODN(M)
      RCUS(N) = (RCUS(M)+BOD(2,M))*10.**(-AK1(M)*TIN(M))
      RNUS(N) = (RNUS(M)+BODN(M))*10.**(-AKN(M)*TIN(M))
      BODSAT(M) = BODIN(M)-RCUS(N)-RNUS(N)
      Y = AVS(M)*AVA(M)*(X(M)-X(N))*2.7016*1.1**(AVT(M)/2.-10.)/(AVD
     $(M)*SQRT(AMI))
      SATOUT = Q(M)*S(N)*5.39136
      K = 0
      PCTEST = PCTOP(M)
   16 REAER(M) = (1.-.5*(PCTEST+PCTOP(M)))*Y
      Z = (REAER(M)+DOIN(M)-BODSAT(M))/SATOUT
      K = K+1
      IF (K.GT.20) GO TO 29
      IF (ABS(Z-PCTEST).LE..0001) GO TO 17
      PCTEST = Z
      GO TO 16
   17 PCTUS(N) = Z
      PPM(M) = S(M)*PCTOP(M)
   18 DOUS(N) = Z*SATOUT
      BODIN(297) = RCUS(297)+RNUS(297)+BOD(1,297)+BOD(2,297)+BOD(3,297)+
     $BODN(297)
      DOIN(297) = DOUS(297)+QIN(297)*PCTIN(297)*S(297)*5.3913
      PCTOP(297) = (Q(296)*PCTUS(297)+QIN(297)*PCTIN(297))/Q(297)
      PPM(297) = S(297)*PCTOP(297)
C
C     LOADING OUTPUT
C
      WRITE (5,34) TITH,TITT,TITL
      WRITE (5,35)
      DO 19 K=1,KL
         I = IRL(K)
   19 WRITE (5,36) I,X(I),BOD(1,I),BOD(2,I),BOD(3,I),BODN(I),QIN(I),
     $PCTIN(I)
C
C     TEMPERATURE OUTPUT
C
      WRITE (5,34) TITH,TITT,TITL
      WRITE (5,37)
      DO 20 K=1,KT
         I = IRT(K)
   20 WRITE (5,38) I,X(I),T(I),S(I)
C
C     REACH OUTPUT
C
      WRITE (5,34) TITH,TITT,TITL
      DO 27 KPAGE=1,5
         IF (KPAGE.NE.1) WRITE (5,39)
         GO TO (21,22,23,24,25), KPAGE
   21    MT = 1
         MB = 67
         GO TO 26
   22    MT = 68
         MB = 141
         GO TO 26
   23    MT = 142
         MB = 215
         GO TO 26
   24    MT = 216
         MB = 289
         GO TO 26
   25    MT = 290
         MB = 296
   26    WRITE (5,40)
   27 WRITE (5,41) (I,X(I),AVA(I),AVD(I),AVT(I),Q(I),V(I),AK1(I),AKN(I),
     $BODIN(I),BODSAT(I),RCUS(I+1),RNUS(I+1),DOIN(I),REAER(I),DOUS(I+1),
     $TTO(I),PCTOP(I),PPM(I),I=MT,MB)
```

TABLE B-23 (continued).

```
      I = 297
      WRITE (5,42) I,X(I),Q(I),BODIN(I),DOIN(I),TTO(I),PCTOP(I),PPM(I)
C
C     PLOT OUTPUT
C
      WRITE (4,43) (I,X(I),XKM(I),PPM(I),I=1,297)
      CALL EXIT
C
C     ERROR TERMINATIONS
C
   28 WRITE (5,44) XTEST
      CALL EXIT
   29 WRITE (5,45) N
      CALL EXIT
C
   30 FORMAT (A8)
   31 FORMAT (3X,F6.2,F7.0,F5.0,F8.2)
   32 FORMAT (2F10.0)
   33 FORMAT (F6.2,4F10.0,F6.2)
   34 FORMAT (≠1WILLAMETTE DISSOLVED OXYGEN MODEL≠/// HYDRAULIC DATA FRO
     $M FILE ≠,A8/≠ TEMPERATURE DATA FROM FILE ≠,A8/≠ LOADING DATA FROM
     $FILE ≠,A8//)
   35 FORMAT (15X,≠**********LBS OF BOD DISCHARGED DAILY**********     *ADD
     $ED FLOW*≠///≠ REACH  MILE   IMMEDIATE   COLLOIDAL   SETTLEABLE  NITR
     $OGENOUS≠,5X,≠CFS     PCT≠/9X,≠PT≠,16X,≠DISSOLVED     SOLIDS≠,27X,
     $≠SAT≠/)
   36 FORMAT (I5,F7.2,4F12.0,F9.0,F7.2)
   37 FORMAT (≠ REACH  MILE  TEMPERATURE  DO SAT≠/9X,≠PT≠,6X,≠C≠,9X,
     $≠PPM≠/)
   38 FORMAT (I5,F7.2,F10.2,F11.3)
   39 FORMAT (≠1≠)
   40 FORMAT (F1X,≠*****************BALANCE LBS PER DAY***************
     $***TOP OF REACH***≠//16X,≠***AVERAGE REACH CONDITIONS***   CONSTAN
     $TS    ************BOD*************    **DISSOLVED OXYGEN**≠,11X,
     $≠****DO****≠///≠ REACH  MILE      XSEC  DEPTH  TEMP     Q    VEL    KC
     $     KN   INITIAL SATIS-     FINAL       INITIAL REAER  FINAL   TIM
     $E    PCT     PPM≠/9X,≠PT        SQFT    FT       C     CFS   MPD    BASE
     $ 10≠,12X,≠ FIED    CARB    NITR≠,26X,≠DAYS      SAT≠/)
   41 FORMAT (I5,F7.2,F8.0,F6.2,F7.2,F7.0,F6.2,F6.3,F6.3,F9.0,F6.0,F8.0,
     *F7.0,F9.0,F6.0,F8.0,F7.3,F7.2,F7.3)
   42 FORMAT (I5,F7.2,21X,F7.0,18X,F9.0,21X,F9.0,14X,F7.3,F7.2,F7.3)
   43 FORMAT (I4,3F10.4)
   44 FORMAT (≠ NO REACH STARTS AT ≠,F6.2)
   45 FORMAT (≠ K OVER 20 WHEN N =≠,I4)
      END
```

TABLE B-24. EXAMPLES OF COMPUTER OUTPUT

```
WILLAMETTE DISSOLVED OXYGEN MODEL

HYDRAULIC DATA FROM FILE H73
TEMPERATURE DATA FROM FILE T20
LOADING DATA FROM FILE L73

              *********LBS OF BOD DISCHARGED DAILY***********    *ADDED FLOW*

REACH  MILE   IMMEDIATE   COLLOIDAL  SETTLEABLE  NITROGENOUS     CFS     PCT
        PT                DISSOLVED    SOLIDS                            SAT

    1  86.50          0       98523           0        60574    6541     .95
    4  85.00          0       20340           0        86000      19     .50
    5  84.00          0           0           0            0      46     .93
    9  81.00          0        -569           0         -877     -70     .90
   10  80.00          0          20           0           34       0     .50
   11  79.00          0           4           0            9       0       0
   12  77.90          0       20040           0        12900      34     .10
   22  70.00          0        -799           0         -757     -70     .95
   34  60.00          0        -659           0         -383     -70     .85
   40  55.00          0         982           0          774      37     .90
   56  51.80          0          30           0            0       0     .50
   62  50.50          0         230           0          434       1     .50
   65  50.00          0        -519           0         -292     -70     .85
   66  49.90          0       12024           0            0      14     .50
  105  42.00          0          23           0           26       0     .50
  114  40.20          0           2           0            4       0     .50
  115  40.00          0        -511           0         -318     -70     .85
  116  39.50          0          43           0           64       0     .50
  120  39.00          0          43           0          245       0     .50
  136  35.75          0         876           0          886      77    1.00
  151  33.00          0         142           0          245       1     .50
  159  31.60          0          10           0           26       0     .50
  174  29.45          0        4875           0         2012      36     .90
  178  28.80          0        8015           0            0      23     .50
  180  27.80          0          70           0          116       0     .50
  181  27.60          0       16032           0            0      21     .50
  194  25.21          0         641           0         1795       4     .50
  196  24.82          0        5605           0          589     853     .96
  199  24.14          0         263           0          254       1     .50
  210  21.97          0          30           0          357       1     .50
  217  20.23          0         699           0         2769       6     .50
  218  19.90          0        1052           0         1221       3     .50
  227  18.40          0          28           0           86       1     .80
  228  18.39          0         401           0         1221       3     .50
  259  12.94       6000           0           0            0       0       0
  276   9.20       6000           0           0            0       0       0
  281   8.23       6000           0           0            0       0       0
  286   7.20          0           0           0          645      57     .75
  287   7.00          0        3006           0            0       0     .75
  291   6.20       6000           0           0            0       0       0
  296   5.20       6000           0           0            0       0       0
```

```
WILLAMETTE DISSOLVED OXYGEN MODEL

HYDRAULIC DATA FROM FILE H73
TEMPERATURE DATA FROM FILE T20
LOADING DATA FROM FILE L73

REACH  MILE   TEMPERATURE   DO SAT
        PT         C          PPM

    1  86.50     20.00       9.178
   48  53.40     20.20       9.139
   49  53.20     20.40       9.100
   50  53.00     20.60       9.062
   51  52.80     20.80       9.024
   52  52.60     21.00       8.986
   86  45.95     21.20       8.949
   87  45.60     21.40       8.911
   88  45.40     21.60       8.874
   89  45.20     21.80       8.837
   90  45.00     22.00       8.801
  126  37.80     22.20       8.765
  127  37.60     22.40       8.729
  128  37.40     22.60       8.693
  129  37.20     22.80       8.657
  130  37.00     23.00       8.622
  188  26.37     23.10       8.605
  189  26.20     23.20       8.587
  190  26.00     23.30       8.570
  191  25.74     23.40       8.552
  192  25.56     23.50       8.535
```

TABLE B-24 (continued)

```
                                                                       ****************BALANCE LBS PER DAY****************   ***TOP OF REACH***
                ***AVERAGE REACH CONDITIONS***      CONSTANTS     *************BOD*************     **DISSOLVED OXYGEN**              ****DO****
REACH   MILE    XSEC   DEPTH   TEMP     Q     VEL    KC      KN   INITIAL SATIS-     FINAL        INITIAL REAER   FINAL     TIME    PCT    PPM
         PT     SQFT    FT       C     CFS    MPD    BASE 10               FIED   CARB    NITR                               DAYS    SAT

    1   86.50    2361   6.74   20.00   6541  45.33  .050   .400   159097  1030    98348   59719   275376   212  274257       0    .85  7.801
    2   85.90    2362   7.33   20.00   6541  45.32  .050   .400   158066   874    98193   58995   274257   166  273540    .015    .85  7.779
    3   85.20    2336   6.09   20.00   6541  45.82  .050   .400   157193   286    98149   59758   273540    71  273332    .029    .85  7.759
    4   85.00    2315   5.02   20.00   6560  46.37  .050   .400   262947  3140   117895  141911   273914   471  271146    .033    .84  7.742
    5   84.00    1980   3.96   20.00   6606  57.50  .050   .400   259807   251   117872  141684   273194    56  273000    .055    .84  7.671
    6   83.90    1640   3.13   20.00   6606  75.07  .050   .400   259556  1719   117709  140128   273003   524  271806    .056    .84  7.665
    7   83.00    1639   2.75   20.00   6606  75.12  .050   .400   257837  1889   117529  139421   271806   711  270629    .068    .83  7.632
    8   82.03    1635   2.91   20.00   6606  75.33  .050   .400   255950  1862   117350  136738   270629   670  269437    .082    .83  7.599
    9   81.00    1631   3.46   20.00   6536  74.74  .050   .400   252642  1844   116601  134197   265320   540  265016    .095    .82  7.558
   10   80.00    1632   4.93   20.00   6536  74.71  .050   .400   250852  1826   116441  132597   265019   350  263543    .108    .82  7.521
   11   79.00    1632   5.39   20.00   6536  74.71  .050   .400   249041  1983   116249  130910   263543   339  261900    .122    .81  7.479
   12   77.90    1705   4.96   20.00   6570  53.03  .050   .400   279999   235   136263  143500   262066    43  261575    .136    .81  7.339
   13   77.80    1991   5.93   20.00   6570  54.29  .050   .400   279763  2166   136032  141565   261875   322  260031    .139    .81  7.393
   14   77.00    1991   5.96   20.00   6570  54.27  .050   .400   277597  2671   135744  139193   260031   403  257764    .153    .80  7.341
   15   76.00    1991   5.09   20.00   6570  54.29  .050   .400   274927  2629   135456  136961   257764   519  255653    .171    .79  7.277
   16   75.00    1993   5.23   20.00   6570  54.30  .050   .400   272297  2589   135169  134519   255653   515  253579    .190    .79  7.215
   17   74.00    1990   5.50   20.00   6570  54.33  .050   .400   269709  2549   134883  132276   253579   494  251523    .208    .78  7.159
   18   73.00    1980   6.97   20.00   6570  54.33  .050   .400   267159  2511   134597  130352   251523   582  249595    .226    .77  7.101
   19   72.00    1961   4.75   20.00   6570  54.94  .050   .400   264649   493   134541  129615   249595   125  249227    .245    .77  7.047
   20   71.90    1961   5.01   20.00   6570  55.39  .050   .400   264156  1936   134317  127302   249227   465  247755    .248    .77  7.036
   21   71.00    1935   6.06   20.00   6570  55.56  .050   .400   262220  2301   134039  125900   247755   456  245930    .263    .76  6.995
   22   70.00    1929   7.29   20.00   6500  55.14  .050   .400   259294  2369   132964  122371   242395   364  240931    .281    .76  6.931
   23   69.00    1929   6.92   20.00   6500  55.14  .050   .400   255935  2314   132685  120934   240931   408  239956    .299    .75  6.875
   24   68.00    1929   5.92   20.00   6500  55.14  .050   .400   253620  2280   132409  118331   239956   518  237226    .317    .74  6.825
   25   67.00    1929   5.57   20.00   6500  55.14  .050   .400   251340  2245   132133  116961   237226   561  235539    .335    .74  6.770
   26   66.00    1929   5.56   20.00   6500  55.14  .050   .400   249094  2213   131858  115223   235539   577  233902    .353    .73  6.722
   27   65.00    2189   6.22   20.00   6500  49.62  .050   .400   246881   497   131795  114588   233902   113  233517    .372    .73  6.675
   28   64.50    2446   7.93   20.00   6500  43.49  .050   .400   246383  2204   131516  112663   233517   376  231699    .376    .73  6.664
   29   64.00    2446   7.36   20.00   6500  43.49  .050   .400   244179  2709   131169  110302   231699   519  229500    .394    .72  6.612
   30   63.00    2446   6.62   20.00   6500  43.49  .050   .400   241470  2659   130822  107990   229500   615  227456    .417    .71  6.549
   31   62.00    2445   6.99   20.00   6500  43.49  .050   .400   238811  2609   130476  105726   227456   596  225441    .440    .71  6.491
   32   61.00    2447   8.20   20.00   6500  43.47  .050   .400   236202  2053   130200  103350   225441   383  223771    .463    .70  6.433
   33   60.20    1929   6.93   20.00   6500  55.14  .050   .400   234149   346   130148  103621   223771    93  223686    .482    .70  6.396
   34   60.00    1209   3.79   20.00   6410  87.05  .050   .400   232727  1258   129319  102152   220540   697  219990    .485    .69  6.362
   35   59.00    1209   4.57   20.00   6410  87.06  .050   .400   231470  1246   129147  101077   219993   545  219279    .496    .69  6.346
   36   58.00    1209   5.75   20.00   6410  87.03  .050   .400   230224  1235   128976  100313   219279   396  218440    .508    .69  6.326
   37   57.00    1209   5.75   20.00   6430  87.03  .050   .400   228989  1223   128856   99360   218440   399  217616    .519    .69  6.301
   38   56.00    1233   5.95   20.00   6430  85.57  .050   .400   227765   987   128667   99111   217616   320  216949    .531    .69  6.278
   39   55.20    2283   7.51   20.00   6433  45.99  .020      0   226778    26   128641   99111   216949   166  217030    .540    .68  6.258
   40   55.00    2615   7.35   20.00   6467  40.47  .020      0   228509    29   129594   98985   219673   126  219772    .545    .69  6.272
   41   54.90    2115   5.11   20.00   6467  50.83  .020      0   228679    24   129570   98985   219772   165  219914    .550    .69  6.275
   42   54.60    3687   5.46   20.00   6467  30.35  .020      0   228455    29   129540   98985   219914   169  219056    .554    .69  6.279
   43   54.45    5137   9.56   20.00   6467  20.50  .020      0   228426    72   129469   98985   219056   216  219195    .559    .69  6.283
   44   54.20    8462  15.59   20.00   6467  12.51  .020      0   228353    95   129373   98985   219195   146  219246    .571    .69  6.287
   45   54.00    9359  13.91   20.00   6467  13.13  .020      0   228258    91   129282   98985   219246   165  219322    .587    .69  6.289
   46   53.80    6597   6.95   20.00   6467  22.53  .020      0   228167    53   129229   98985   219322   244  219513    .602    .69  6.291
   47   53.60    4031   5.59   20.10   6467  26.25  .020      0   228115    46   129194   98985   219513   270  219737    .611    .69  6.296
   48   53.40    3394   5.63   20.30   6467  31.13  .020      0   228069    39   129145   98985   219737   240  219939    .618    .69  6.303
   49   53.20    4551   5.13   20.50   6467  22.75  .020      0   228030    53   129091   98985   219939   162  220047    .625    .69  6.306
   50   53.00    5502  11.58   20.70   6467  15.39  .021      0   227977    65   129026   98985   220047   142  220124    .634    .70  6.311
   51   52.80    9539  14.99   20.90   6467  10.91  .021      0   227912   113   128914   98985   220124   150  220161    .646    .70  6.314
   52   52.60   11354  21.51   21.00   6467   9.31  .021      0   227799   133   128780   98985   220161   132  220159    .662    .70  6.315
   53   52.40    7553  14.37   21.00   6467  14.00  .021      0   227666    89   128692   98985   220159   144  220216    .684    .70  6.315
   54   52.20    6164   9.23   21.00   6467  17.17  .021      0   227577    56   128637   98985   220216   193  220343    .698    .70  6.316
   55   52.05    7124   9.62   21.00   6467  14.85  .021      0   227523   104   128533   98985   220343   284  220523    .707    .70  6.322
   56   51.90    7339  11.19   21.00   6467  13.33  .021      0   227449    93   128470   98985   220525   208  220640    .724    .70  6.325
   57   51.60    9064  10.91   21.00   6467  13.22  .021      0   227356    94   128376   98985   220640   218  220765    .739    .70  6.328
   58   51.40    9350  11.82   21.00   6467  11.32  .021      0   227262   219   128159   98985   220765   453  221000    .756    .70  6.332
   59   51.00   12629  14.22   21.00   6467   8.39  .021      0   227043   147   128010   98985   221000   241  221093    .789    .71  6.339
   60   50.90   11763  14.15   21.00   6467   9.00  .021      0   226896   103   127908   98985   221093   169  221160    .813    .71  6.341
   61   50.65    9173  11.94   21.00   6467  12.95  .021      0   226793    71   127836   98985   221160   146  221235    .830    .71  6.343
   62   50.55    7561  10.94   21.00   6468  13.92  .021      0   227306    44   129022   99326   221257   101  221314    .841    .71  6.345
   63   50.40   10561  15.45   21.00   6469  10.02  .021      0   227342   123   127899   99320   221314   176  221367    .849    .71  6.347
   64   50.20   11979  21.21   21.00   6469   8.91  .021      0   227219   138   127761   99320   221367   139  221367    .868    .71  6.348
   65   50.00   13793  21.79   21.00   6399   9.69  .021      0   226269   127   127115   99327   218495   123  218491    .891    .70  6.334
   66   49.90   12322  23.73   21.00   6412   8.52  .021      0   238167   157   138982   99327   218926   128  218796    .912    .70  6.336
   67   49.60   11914  22.91   21.00   6412   8.81  .021      0   238009   152   138830   99327   218796   128  218772    .935    .70  6.329
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TABLE B-24 (continued)

REACH	MILE PT	XSEC SQFT	DEPTH FT	TEMP C	Q CFS	VEL MPD	KC BASE 10	KN	INITIAL	SATIS-FIED	FINAL CARB	FINAL NITR	INITIAL	REAER	FINAL	TIME DAYS	PCT SAT	PPM
68	49.40	10591	21.20	21.00	6412	9.91	.021	0	237857	135	138695	99027	218772	125	218762	.958	.70	6.329
69	49.20	12057	22.25	21.00	6412	8.70	.021	0	237722	154	138541	99027	218762	134	218743	.978	.70	6.328
70	49.00	14147	24.00	21.00	6412	7.42	.021	0	237568	180	138361	99027	218743	145	218707	1.001	.70	6.328
71	48.80	12709	24.90	21.00	6412	8.26	.021	0	237388	161	138199	99027	218707	125	218670	1.028	.70	6.327
72	48.60	10477	22.05	21.00	6412	10.02	.021	0	237227	133	138066	99027	218670	118	218655	1.052	.70	6.326
73	48.40	9893	19.21	21.00	6412	10.61	.021	0	237094	125	137941	99027	218655	140	218670	1.072	.70	6.325
74	48.20	10205	15.39	21.00	6412	10.29	.021	0	236968	129	137812	99027	218670	164	218704	1.091	.70	6.326
75	48.00	10258	15.56	21.00	6412	10.23	.021	0	236839	162	137649	99027	218704	220	218762	1.110	.70	6.327
76	47.75	9956	15.83	21.00	6412	10.54	.021	0	236677	94	137555	99027	218762	125	218792	1.135	.70	6.329
77	47.60	10453	16.09	21.00	6412	10.04	.021	0	236582	132	137423	99027	218792	172	218832	1.149	.70	6.329
78	47.40	12111	19.51	21.00	6412	8.66	.021	0	236450	153	137270	99027	218832	157	218836	1.169	.70	6.330
79	47.20	12940	22.90	21.00	6412	8.11	.021	0	236297	163	137107	99027	218836	139	218813	1.192	.70	6.330
80	47.00	12080	23.31	21.00	6412	8.69	.021	0	236134	152	136955	99027	218813	128	218798	1.217	.70	6.330
81	46.80	12719	24.32	21.00	6412	8.25	.021	0	235982	200	136755	99027	218798	162	218750	1.240	.70	6.329
82	46.55	14561	24.97	21.00	6412	7.21	.021	0	235782	137	136617	99027	218750	107	218720	1.270	.70	6.329
83	46.40	14637	23.50	21.00	6412	7.17	.021	0	235645	184	136434	99027	218720	153	218690	1.291	.70	6.327
84	46.20	16533	25.43	21.00	6412	6.35	.021	0	235461	207	136227	99027	218690	158	218641	1.319	.70	6.326
85	46.00	19305	30.95	21.10	6412	5.44	.021	0	235254	182	136045	99027	218641	111	218570	1.350	.70	6.325
86	45.85	17493	28.83	21.30	6412	6.00	.021	0	235072	277	135768	99027	218570	197	218480	1.379	.71	6.323
87	45.60	13919	25.04	21.50	6412	7.54	.021	0	234795	178	135590	99027	218480	134	218437	1.420	.71	6.320
88	45.40	14556	24.81	21.70	6412	7.21	.022	0	234618	187	135403	99027	218437	141	218391	1.446	.71	6.319
89	45.20	15383	20.54	21.90	6412	6.82	.022	0	234430	199	135204	99027	218391	135	218376	1.474	.71	6.317
90	45.00	13579	21.64	22.00	6412	7.73	.022	0	234231	221	134983	99027	218376	191	218347	1.503	.72	6.317
91	44.75	14519	26.59	22.00	6412	7.23	.022	0	234010	188	134795	99027	218347	130	218288	1.535	.72	6.316
92	44.55	16006	27.94	22.00	6412	6.56	.022	0	233822	156	134639	99027	218288	102	218234	1.563	.72	6.315
93	44.40	16894	27.35	22.00	6412	6.21	.022	0	233666	219	134420	99027	218234	146	218162	1.586	.72	6.313
94	44.20	17497	29.39	22.00	6412	6.00	.022	0	233448	170	134251	99027	218162	109	218101	1.618	.72	6.311
95	44.05	17487	30.41	22.00	6412	6.00	.022	0	233278	282	133969	99027	218101	169	217988	1.643	.72	6.309
96	43.80	17582	30.54	22.00	6412	5.97	.022	0	232996	226	133742	99027	217988	135	217896	1.685	.72	6.306
97	43.60	16875	27.59	22.00	6412	6.22	.022	0	232769	217	133525	99027	217896	145	217825	1.718	.72	6.303
98	43.40	16803	27.47	22.00	6412	6.24	.022	0	232552	216	133309	99027	217825	145	217754	1.751	.72	6.301
99	43.20	15361	26.75	22.00	6412	6.83	.022	0	232337	197	133113	99027	217754	137	217695	1.783	.72	6.299
100	43.00	16891	29.41	22.00	6412	6.21	.022	0	232140	216	132896	99027	217695	136	217614	1.812	.72	6.297
101	42.80	18172	29.32	22.00	6412	5.77	.022	0	231924	232	132664	99027	217614	147	217529	1.844	.72	6.295
102	42.60	14944	23.75	22.00	6412	7.02	.022	0	231692	191	132474	99027	217529	153	217491	1.879	.71	6.293
103	42.40	15259	27.09	22.00	6412	6.88	.022	0	231501	194	132279	99027	217491	135	217432	1.907	.71	6.291
104	42.20	14739	25.21	22.00	6412	7.12	.022	0	231307	187	132092	99027	217432	141	217385	1.936	.71	6.293
105	42.00	15031	24.39	22.00	6412	6.98	.022	0	231165	191	131921	99053	217387	152	217347	1.964	.71	6.289
106	41.80	16480	29.95	22.00	6412	6.37	.022	0	230974	209	131712	99053	217347	136	217274	1.993	.71	6.287
107	41.60	14543	26.57	22.00	6412	7.21	.022	0	230765	184	131528	99053	217274	131	217221	2.024	.71	6.285
108	41.40	15726	24.90	22.00	6412	6.67	.022	0	230581	199	131329	99053	217221	153	217175	2.052	.71	6.284
109	41.20	16874	24.52	22.00	6412	6.22	.022	0	230382	213	131116	99053	217175	166	217128	2.082	.71	6.282
110	41.00	14345	21.54	22.00	6412	7.31	.022	0	230169	181	130935	99053	217128	165	217112	2.114	.71	6.281
111	40.80	13781	21.73	22.00	6412	7.61	.022	0	229988	174	130761	99053	217112	157	217096	2.142	.71	6.280
112	40.60	15900	26.11	22.00	6412	6.60	.022	0	229815	200	130561	99053	217096	147	217063	2.168	.71	6.280
113	40.40	16025	26.29	22.00	6412	6.55	.022	0	229615	201	130360	99053	217043	147	216949	2.198	.71	6.279
114	40.20	14075	22.35	22.00	6412	7.45	.022	0	229420	176	130196	99357	216949	155	216968	2.229	.71	6.277
115	40.00	15895	25.31	22.00	6342	6.53	.022	0	229414	190	129495	98739	214145	165	214104	2.256	.71	6.263
116	39.80	15852	27.27	22.00	6342	6.55	.022	0	228329	200	129325	99406	214104	141	214045	2.285	.71	6.262
117	39.60	14489	23.83	22.00	6342	7.16	.022	0	228129	182	129143	99406	214045	150	214012	2.315	.71	6.260
118	39.40	13471	21.52	22.00	6342	7.70	.022	0	227947	127	129016	99406	214012	117	214003	2.343	.71	6.259
119	39.25	13287	21.43	22.00	6342	7.81	.022	0	227820	208	128808	99406	214003	134	213994	2.363	.71	6.259
120	39.00	12642	21.97	22.00	6342	8.21	.022	0	227497	159	128650	99349	213994	150	213976	2.395	.71	6.258
121	38.75	13409	23.24	22.00	6342	7.74	.022	0	227699	125	128524	99349	213976	127	213957	2.425	.71	6.258
122	38.60	16847	26.99	22.00	6342	6.16	.022	0	227573	210	128314	99349	213957	152	213899	2.446	.71	6.257
123	38.40	17951	30.03	22.00	6342	5.78	.022	0	227363	224	128090	99349	213899	143	213918	2.477	.71	6.255
124	38.20	17172	30.67	22.00	6342	6.04	.022	0	227139	214	127876	99349	213918	134	213739	2.511	.71	6.253
125	38.00	17529	31.32	22.10	6342	5.92	.022	0	226925	219	127657	99349	213739	134	213653	2.545	.71	6.251
126	37.80	17763	29.95	22.30	6342	5.84	.022	0	226706	224	127434	99349	213653	142	213572	2.578	.71	6.248
127	37.60	17552	26.04	22.50	6342	5.91	.022	0	226483	222	127211	99349	213572	163	213513	2.613	.72	6.246
128	37.40	16692	24.01	22.70	6342	6.22	.023	0	226260	213	126998	99349	213513	169	213469	2.646	.72	6.244
129	37.20	15326	22.97	22.90	6342	6.77	.023	0	226047	197	126801	99349	213469	163	213435	2.679	.72	6.243
130	37.00	14265	21.95	23.00	6342	7.28	.023	0	225850	184	126617	99349	213435	159	213410	2.708	.72	6.242
131	36.80	15093	24.09	23.00	6342	6.88	.023	0	225666	194	126422	99349	213410	152	213367	2.736	.72	6.241
132	36.60	16406	25.32	23.00	6342	6.33	.023	0	225471	211	126211	99349	213367	151	213307	2.765	.72	6.240
133	36.40	16220	23.51	23.00	6342	6.40	.023	0	225260	209	126003	99349	213307	167	213265	2.796	.72	6.239
134	36.20	16855	27.97	23.00	6342	6.16	.023	0	225052	216	125787	99349	213265	143	213192	2.828	.72	6.237
135	36.00	16148	29.29	23.00	6342	6.43	.023	0	224836	259	125528	99349	213192	164	213097	2.860	.72	6.235
136	35.75	12919	22.01	23.00	6419	8.13	.023	0	226339	123	126290	99935	216676	107	216659	2.899	.73	6.261
137	35.60	13725	21.41	23.00	6419	7.65	.023	0	226215	131	126149	99935	216659	117	216646	2.918	.73	6.263
138	35.45	15125	22.99	23.00	6419	6.95	.023	0	226084	240	125910	99935	216646	199	216606	2.937	.73	6.260
139	35.20	15198	27.09	23.00	6419	6.91	.023	0	225844	192	125717	99935	216606	133	216546	2.973	.73	6.259
140	35.00	18205	31.67	23.00	6419	5.77	.023	0	225652	230	125487	99935	216546	134	216449	3.002	.73	6.257
141	34.80	18241	26.95	23.00	6419	5.76	.023	0	225422	230	125257	99935	216449	161	216380	3.037	.73	6.254

TABLE B-24 (continued)

REACH	MILE PT	XSEC SQFT	DEPTH FT	TEMP C	Q CFS	VEL MPD	KC BASE 10	KN	INITIAL	SATIS-FIED	FINAL CARB	FINAL NITR	INITIAL	REAER	FINAL	TIME DAYS	PCT SAT	PPM
142	34.60	15041	19.76	23.00	6419	6.97	.023	0	225192	190	125067	99935	216380	189	216380	3.071	.73	6.252
143	34.40	17789	27.67	23.00	6419	5.91	.023	0	225002	157	124910	99935	216380	106	216329	3.100	.73	6.252
144	34.25	19655	31.35	23.00	6419	5.34	.023	0	224845	74	124836	99935	216329	44	216299	3.124	.72	6.251
145	34.20	24953	31.20	23.00	6419	4.23	.023	0	224771	312	124526	99935	216299	196	216174	3.135	.72	6.250
146	34.00	24479	33.92	23.00	6419	4.30	.023	0	224459	306	124219	99935	216174	168	216035	3.182	.72	6.246
147	33.80	15358	26.46	23.00	6419	6.86	.023	0	224153	192	124027	99935	216035	136	215990	3.229	.72	6.242
148	33.60	10920	16.74	23.00	6419	9.62	.023	0	223961	204	123822	99935	215990	253	216029	3.258	.72	6.240
149	33.30	12720	11.71	23.00	6419	8.26	.023	0	223757	198	123624	99935	216029	314	216145	3.289	.72	6.242
150	33.05	17055	17.46	23.00	6419	6.16	.023	0	223559	53	123571	99935	216145	62	216156	3.328	.72	6.245
151	33.00	15516	16.99	23.00	6419	6.77	.023	0	223896	193	123521	100180	216166	236	216230	3.328	.72	6.245
152	32.80	13645	16.74	23.00	6420	7.70	.023	0	223701	169	123351	100180	216229	210	216248	3.357	.72	6.247
153	32.60	20049	25.86	23.00	6420	5.24	.023	0	223531	186	123165	100180	216248	144	216205	3.383	.72	6.248
154	32.45	26913	42.77	23.00	6420	3.92	.023	0	223345	83	123082	100180	216205	35	216157	3.412	.72	6.246
155	32.40	21764	37.95	23.00	6420	4.84	.023	0	223262	201	122890	100180	216157	98	216056	3.425	.72	6.245
156	32.25	11740	15.41	23.00	6420	8.95	.023	0	223060	145	122735	100180	216056	208	216109	3.456	.72	6.242
157	32.05	8651	9.63	23.00	6420	12.14	.023	0	222915	133	122602	100180	216109	343	216315	3.478	.72	6.246
158	31.80	16336	17.99	23.00	6420	6.43	.023	0	222782	201	122400	100180	216315	231	216366	3.499	.72	6.250
159	31.60	20751	27.94	23.00	6420	5.06	.023	0	222616	230	122181	100206	216367	158	216275	3.530	.72	6.251
160	31.42	25601	37.41	23.00	6420	3.95	.023	0	222386	359	121821	100206	216275	179	216095	3.565	.72	6.249
161	31.20	26185	33.57	23.00	6420	4.01	.023	0	222027	321	121501	100206	216095	181	215956	3.621	.72	6.243
162	31.00	21397	29.65	23.00	6420	4.91	.023	0	221706	261	121240	100206	215956	170	215866	3.671	.72	6.239
163	30.80	17263	22.29	23.00	6420	6.11	.023	0	221445	252	120948	100206	215866	227	215869	3.712	.72	6.237
164	30.55	9748	15.34	23.00	6420	10.73	.023	0	221196	216	120774	100206	215869	302	215927	3.751	.72	6.236
165	30.20	13157	39.72	23.00	6420	7.99	.023	0	220979	160	120614	100206	215927	70	215865	3.786	.72	6.238
166	30.00	16750	38.75	23.00	6420	7.12	.023	0	220819	179	120435	100206	215865	97	215753	3.809	.72	6.236
167	29.90	17768	19.59	23.00	6420	5.91	.023	0	220641	215	120220	100206	215753	227	215765	3.838	.72	6.233
168	29.60	24765	20.92	23.00	6420	4.25	.023	0	220425	298	119921	100206	215765	292	215760	3.871	.72	6.234
169	29.40	25923	22.97	23.00	6420	4.05	.023	0	220127	312	119609	100206	215763	275	215722	3.910	.72	6.234
170	29.20	23575	19.67	23.00	6420	4.45	.023	0	219815	287	119322	100206	215722	308	215743	3.969	.72	6.232
171	29.00	19572	15.73	23.00	6420	5.36	.023	0	219528	118	119204	100206	215743	165	215790	4.013	.72	6.233
172	28.90	19992	16.73	23.00	6420	5.26	.023	0	219410	299	118905	100206	215790	396	215877	4.032	.72	6.234
173	28.65	27765	30.35	23.00	6420	3.79	.023	0	219110	331	118573	100206	215877	215	215761	4.079	.72	6.237
174	28.45	32135	42.01	23.00	6456	3.29	.023	0	225667	198	123251	102218	217267	46	217156	4.132	.72	6.242
175	28.35	30339	39.99	23.00	6456	3.49	.023	0	225469	374	122877	102218	217156	172	216953	4.163	.72	6.239
176	28.15	30052	35.67	23.00	6456	3.52	.023	0	225095	240	122638	102218	216953	127	216840	4.220	.72	6.233
177	28.02	31073	33.26	23.00	6456	3.40	.023	0	224856	39	122599	102218	216840	22	216826	4.257	.72	6.234
178	28.00	30317	31.59	23.00	6473	3.50	.023	0	232833	276	130339	102218	217356	159	217239	4.263	.72	6.223
179	27.85	29936	30.59	23.00	6479	3.55	.023	0	232557	116	130223	102218	217239	69	217192	4.303	.72	6.219
180	27.80	30495	33.56	23.00	6479	3.48	.023	0	232627	396	129898	102336	217159	237	217061	4.329	.72	6.218
181	27.63	30421	31.78	23.00	6503	3.50	.023	0	249264	461	145449	102336	217526	227	217313	4.377	.72	6.207
182	27.40	29709	35.19	23.00	6500	3.71	.023	0	247923	615	145075	102336	217313	192	217091	4.435	.72	6.201
183	27.20	29793	32.69	23.00	6500	3.73	.023	0	247669	614	144660	102336	217091	211	216887	4.489	.72	6.195
184	27.00	16337	33.07	23.00	6500	6.51	.023	0	246996	12	144649	102336	216887	11	216897	4.543	.72	6.199
185	26.99	2002	16.93	23.00	6500	53.13	.023	0	246993	66	144592	102336	231339	120	231401	4.546	.72	6.189
186	26.53	6996	19.99	23.00	6500	15.20	.023	0	246916	5	144577	102336	231401	4	231400	4.553	.77	6.633
187	26.37	10675	12.65	23.05	6500	9.95	.023	0	246911	115	144462	102336	231400	56	231361	4.553	.77	6.663
188	26.33	15679	44.39	23.15	6503	6.85	.023	0	246796	170	144272	102336	231361	63	231216	4.569	.77	6.661
189	26.20	16466	63.22	23.25	6509	6.45	.023	0	246626	239	144036	102336	231216	98	231065	4.593	.77	6.598
190	26.00	12635	76.67	23.35	6503	8.55	.023	0	246369	235	143799	102336	231065	189	231020	4.626	.77	6.593
191	25.74	13211	18.43	23.45	6500	8.19	.023	0	246133	171	143628	102336	231020	157	231005	4.655	.77	6.592
192	25.56	9731	16.52	23.55	6500	12.74	.023	0	245952	116	143512	102336	231005	121	231011	4.677	.77	6.592
193	25.37	6537	11.63	23.55	6503	21.45	.023	0	245836	53	143459	102336	231011	87	231045	4.692	.77	6.592
194	25.21	4675	11.23	23.50	6504	22.93	.023	0	248219	71	144029	104119	231133	122	231184	4.698	.77	6.593
195	25.00	5074	12.39	23.50	6504	20.99	.023	0	248148	67	143962	104119	231184	95	231211	4.708	.77	[illegible]
196	24.82	6675	11.02	23.50	7357	10.59	.023	0	254275	104	149463	104708	269892	145	269933	4.716	.79	6.779
197	24.59	13721	17.71	23.50	7357	9.11	.023	0	254171	213	149250	104708	269933	201	269921	4.729	.79	6.786
198	24.36	15643	23.25	23.50	7357	7.91	.023	0	253958	267	149644	104708	269921	166	269991	4.755	.79	6.780
199	24.16	13973	23.79	23.50	7358	6.61	.023	0	254267	131	149175	104961	269897	102	269868	4.781	.79	6.779
200	24.00	19152	27.43	23.50	7359	6.29	.023	0	254136	205	148970	104961	269869	108	269770	4.797	.79	6.778
201	23.86	17225	26.17	23.50	7359	6.99	.023	0	253931	173	148797	104961	269776	104	269761	4.823	.79	6.776
202	23.69	12973	13.52	23.50	7359	9.71	.023	0	253758	132	148665	104961	269761	112	269691	4.844	.79	6.774
203	23.51	12537	21.95	23.50	7358	9.65	.023	0	253626	208	148457	104961	269691	153	269626	4.861	.79	6.773
204	23.29	17562	21.55	23.50	7359	7.05	.023	0	253418	318	148139	104961	269626	217	269525	4.896	.79	6.772
205	23.00	14415	19.36	23.50	7359	8.35	.023	0	253100	211	147928	104961	269525	181	269495	4.926	.79	6.769
206	22.79	9935	25.97	23.50	7358	13.49	.023	0	252889	101	147827	104961	269495	62	269457	4.952	.79	6.769
207	22.61	16552	37.63	23.50	7358	9.57	.023	0	252788	149	147678	104961	269457	60	269367	4.965	.79	6.768
208	22.45	17522	39.65	23.50	7359	6.85	.023	0	252639	210	147468	104961	269367	92	269248	4.986	.79	6.765
209	22.27	21472	43.62	23.50	7359	5.56	.023	0	252429	573	146895	104961	269248	163	267930	5.010	.79	6.762
210	21.97	19936	45.67	23.50	7359	6.07	.023	0	252263	268	146676	105318	267852	93	267697	5.082	.79	6.752
211	21.69	13450	29.05	23.50	7359	6.69	.023	0	251995	201	146476	105318	267697	110	267607	5.113	.79	6.749
212	21.45	17229	65.41	23.50	7359	4.42	.023	0	251796	412	146064	105318	267607	67	267262	5.139	.79	6.745
213	21.23	30933	69.71	23.50	7359	3.89	.023	0	251382	749	145315	105318	267262	112	266626	5.191	.79	6.737
214	20.95	21997	62.12	23.50	7359	5.02	.023	0	250633	282	145034	105318	266626	104	266448	5.286	.79	6.721
215	20.68	26735	66.65	23.50	7359	4.58	.023	0	250352	278	144755	105318	266445	90	266263	5.322	.79	6.716

TABLE B-24 (continued)

REACH	MILE PT	XSEC SQFT	DEPTH FT	TEMP C	Q CFS	VEL MPD	KC	KN	INITIAL	SATIS-FIED	FINAL		INITIAL	REAER	FINAL	TIME DAYS	PCT SAT	PPM
							BASE 10				CARB	NITR						
216	20.52	26703	49.51	23.50	7359	4.51	.023	0	250873	503	144253	105318	264268	148	265936	5.357	.79	6.711
217	20.23	27376	44.72	23.50	7365	4.40	.023	0	253939	586	144365	108087	265543	203	265459	5.421	.79	6.760
218	19.93	30117	38.33	23.50	7367	4.00	.023	0	254726	255	145162	109309	265723	135	265570	5.496	.78	6.693
219	19.77	36515	44.05	23.50	7367	3.32	.023	0	254671	672	144690	109309	265573	149	265246	5.529	.78	6.686
220	19.57	37931	50.41	23.50	7367	3.19	.023	0	253999	617	144273	109309	265246	123	264953	5.589	.78	6.678
221	19.40	40356	55.69	23.50	7367	2.99	.023	0	253582	677	143597	109309	264953	171	264647	5.652	.78	6.671
222	19.14	32749	55.07	23.50	7367	3.69	.023	0	252905	295	143301	109309	264647	77	264278	5.729	.78	6.658
223	19.00	30965	41.59	23.50	7367	4.01	.023	0	252616	276	143031	109309	264228	106	264066	5.767	.78	6.652
224	18.95	46476	46.33	23.50	7367	2.57	.023	0	252340	540	142491	109309	264066	136	263739	5.802	.78	6.648
225	18.68	49660	49.81	23.50	7367	2.46	.023	0	251799	568	141923	109309	263749	147	263329	5.872	.78	6.639
226	18.50	45369	47.52	23.50	7367	2.68	.023	0	251231	287	141636	109309	263329	97	263139	5.946	.78	6.630
227	18.40	45369	47.52	23.50	7368	2.68	.023	0	251059	29	141636	109395	263176	10	263157	5.986	.78	6.625
228	18.39	43658	46.85	23.50	7371	2.97	.023	0	252652	78	141959	110616	263217	27	263166	5.987	.78	6.624
229	18.36	32755	40.41	23.50	7371	3.65	.023	0	252575	396	141563	110616	263166	166	262936	5.997	.78	6.622
230	18.17	28534	34.96	23.50	7371	4.19	.023	0	252179	125	141435	110616	262936	64	262872	6.049	.78	6.617
231	18.10	39461	41.01	23.50	7371	1.97	.023	0	252051	367	141088	110616	262472	146	262669	6.066	.78	6.615
232	17.92	33564	45.64	23.50	7371	3.59	.023	0	251704	603	140685	110616	262669	142	262435	6.111	.77	6.610
233	17.73	32256	45.53	23.50	7371	3.67	.023	0	251101	396	140292	110616	262435	146	262158	6.164	.77	6.603
234	17.56	34633	44.95	23.50	7371	3.39	.023	0	250908	625	139966	110616	262155	141	261876	6.216	.77	6.597
235	17.35	44572	52.17	23.50	7371	2.73	.023	0	250482	531	139335	110616	261876	161	261556	6.272	.77	6.590
236	17.16	56413	54.96	23.50	7371	2.16	.023	0	249951	211	139124	110616	261536	59	261352	6.342	.77	6.583
237	17.10	53223	46.42	23.50	7371	2.27	.023	0	249748	797	138332	110616	261352	290	260951	6.378	.77	6.577
238	16.96	33923	29.95	23.50	7371	3.57	.023	0	248948	377	137955	110616	260851	235	260730	6.476	.77	6.564
239	16.69	30992	40.09	23.50	7371	3.09	.023	0	248571	602	137353	110616	260739	371	260379	6.526	.77	6.561
240	16.43	42376	49.70	23.50	7371	2.45	.023	0	247969	703	136651	110616	260379	239	259915	6.607	.77	6.552
241	16.16	31539	36.55	23.50	7371	3.42	.023	0	247266	309	136342	110616	259915	168	259776	6.762	.77	6.541
242	16.00	34177	24.72	23.50	7371	3.53	.023	0	246959	376	135966	110616	259776	199	259697	6.764	.77	6.537
243	15.82	145116	93.94	23.50	7371	.83	.023	0	246592	2156	133772	110616	259697	248	257752	6.795	.77	6.535
244	15.57	143566	95.09	23.50	7371	.84	.023	0	244144	1542	132236	110616	257752	169	256378	7.096	.76	6.496
245	15.39	33959	29.16	23.50	7371	3.55	.023	0	242446	361	131889	110616	256378	292	256299	7.316	.76	6.457
246	15.22	32313	28.13	23.50	7371	3.71	.023	0	242535	724	131668	110616	256299	169	256229	7.348	.76	6.469
247	15.10	28602	27.35	23.50	7371	4.67	.023	0	242276	687	131176	110616	256229	375	256119	7.398	.76	6.468
248	14.79	22527	29.51	23.50	7371	5.35	.023	0	241790	346	130830	110616	256119	244	256018	7.458	.76	6.465
249	14.52	23366	37.71	23.50	7371	5.41	.023	0	241455	273	130557	110616	256619	134	255933	7.507	.75	6.463
250	14.35	29201	41.23	23.50	7371	4.25	.023	0	241173	280	130277	110616	255983	136	254739	7.546	.75	6.439
251	14.19	36175	31.74	23.50	7371	3.51	.023	0	240873	359	129919	110616	255739	137	255617	7.585	.75	6.436
252	14.00	46972	31.62	23.50	7371	2.69	.023	0	240534	671	129447	110616	255617	316	255460	7.636	.75	6.432
253	13.97	43993	33.53	23.50	7371	2.75	.023	0	240963	635	129912	110616	255463	393	255223	7.703	.75	6.429
254	13.57	39139	34.54	23.50	7371	3.09	.023	0	230629	361	129651	110616	255223	353	255115	7.794	.75	6.423
255	13.51	41566	29.54	23.50	7371	2.97	.023	0	230467	443	129208	110616	255115	326	254996	7.866	.75	6.420
256	13.22	41770	31.43	23.50	7371	2.76	.023	0	230626	552	127656	110616	254396	353	254799	7.918	.75	6.417
257	13.03	41273	37.75	23.50	7371	2.92	.023	0	239072	377	127279	110516	254798	211	254633	7.998	.75	6.412
258	12.95	35497	43.43	23.50	7371	3.23	.023	0	241695	6563	126516	110616	254613	306	254373	8.065	.73	6.409
259	12.57	36165	44.22	23.50	7371	3.32	.023	0	237132	227	125989	110616	254373	113	254260	8.127	.73	6.256
260	12.49	41669	44.39	23.50	7371	2.93	.023	0	236965	561	125749	110616	249260	271	247989	8.160	.73	6.247
261	12.23	44911	52.61	23.50	7371	2.61	.023	0	236324	596	125156	110616	247949	256	247651	8.239	.73	6.241
262	11.99	41123	52.63	23.50	7371	2.91	.023	0	235770	530	124626	110616	247651	211	247313	8.327	.73	6.232
263	11.80	39652	44.94	23.50	7371	3.12	.023	0	235240	367	124259	110616	247333	185	247150	8.405	.73	6.226
264	11.68	47670	41.79	23.50	7371	2.56	.023	0	234973	528	123731	110616	247153	246	246916	8.460	.73	6.219
265	11.60	51656	42.16	23.50	7371	2.35	.023	0	234165	572	123159	110616	246916	317	246661	8.539	.73	6.213
266	11.20	51508	44.14	23.50	7371	2.15	.023	0	237776	557	122602	110616	246661	243	246197	8.626	.73	6.207
267	11.00	55726	47.51	23.50	7371	2.26	.023	0	232216	813	121789	110616	246347	377	245466	8.708	.73	6.200
268	10.73	55166	67.94	23.50	7371	2.19	.023	0	232637	391	121623	110616	245966	197	245763	8.831	.73	6.190
269	10.60	57157	65.73	23.50	7371	2.31	.023	0	232816	567	120811	110616	245763	291	245695	8.890	.72	6.187
270	10.40	61939	56.52	23.50	7371	2.32	.023	0	231449	561	120272	110616	245445	331	245226	8.977	.72	6.177
271	10.20	63926	61.75	23.50	7371	1.89	.023	0	230895	685	119596	110616	245226	391	244917	9.063	.72	6.171
272	10.00	79276	30.96	23.50	7371	1.56	.023	0	210260	836	114750	110616	244917	546	244627	9.169	.72	6.163
273	9.80	70277	35.93	23.50	7371	1.72	.023	0	229366	766	113986	110616	244627	553	244436	9.298	.72	6.156
274	9.60	56681	35.93	23.50	7371	1.86	.023	0	228628	619	117396	110616	244436	667	244262	9.415	.72	6.151
275	9.40	60313	36.55	23.50	7371	2.00	.023	0	228008	633	116751	110616	244262	651	244043	9.512	.72	6.147
276	9.20	71646	42.22	23.50	7371	1.69	.023	0	233367	6766	116036	110616	244098	665	237799	9.612	.72	6.142
277	9.00	95555	55.06	23.50	7371	1.61	.023	0	226622	888	115119	110616	237799	516	237627	9.731	.70	5.985
278	8.80	91554	52.46	23.50	7371	1.29	.023	0	225736	962	114156	110616	237627	626	237346	9.873	.70	5.975
279	8.60	96291	63.92	23.50	7371	1.20	.023	0	224772	961	113195	110616	237946	666	235795	10.028	.70	5.966
280	8.43	89993	66.92	23.50	7371	1.35	.023	0	223911	765	112430	110616	236785	675	236499	10.186	.70	5.959
281	8.23	105703	54.25	23.50	7371	1.15	.023	0	229049	7725	110701	110616	236499	956	229726	10.339	.70	5.951
282	7.93	129573	49.54	23.50	7371	.94	.023	0	221317	637	110064	110616	229726	375	229662	10.596	.68	5.781
283	7.80	113797	44.12	23.50	7371	1.01	.023	0	220680	1171	109893	110616	229662	821	229112	10.703	.68	5.776
284	7.60	59726	42.97	23.50	7371	1.23	.023	0	219509	956	107937	110616	229112	766	229562	10.981	.69	5.765
285	7.40	57741	43.23	23.50	7371	1.37	.023	0	218553	446	107491	110616	228862	623	224639	11.066	.67	5.759
286	7.22	74265	41.92	23.50	7424	1.55	.023	0	218352	763	106348	111261	230614	579	230450	11.269	.67	5.759
287	7.07	64569	41.70	23.50	7424	1.44	.023	0	220615	639	108915	111261	230457	336	233355	11.339	.67	5.756
288	6.80	59634	42.91	23.50	7428	2.05	.023	0	220176	746	108169	111261	230355	555	230163	11.412	.67	5.752
289	6.60	59269	42.62	23.50	7428	2.05	.023	0	219430	569	107600	111261	230163	430	230025	11.539	.67	5.747

TABLE B-24 (continued)

REACH	MILE PT	XSEC SQFT	DEPTH FT	TEMP C	Q CFS	VEL MPD	KC BASE 10	KN	INITIAL	SATIS-FIED	FINAL CARB	FINAL NITR	INITIAL	REAER	FINAL	TIME DAYS	PCT SAT	PPM
290	6.40	56120	61.63	23.50	7626	2.17	.023	0	218861	536	187066	111261	233025	622	229911	11.637	.67	5.744
291	6.20	59925	62.19	23.50	7626	2.07	.023	0	224322	6569	186695	111261	229911	656	223795	11.729	.67	5.761
292	6.00	58393	63.15	23.50	7626	2.09	.023	0	217756	552	185963	111261	223795	661	223646	11.828	.65	5.585
293	5.80	53672	62.69	23.50	7626	2.26	.023	0	217264	585	185438	111261	223646	616	223593	11.926	.65	5.585
294	5.60	59566	62.92	23.50	7626	2.19	.023	0	216699	520	184918	111261	223593	627	223499	12.012	.65	5.583
295	5.40	59136	64.95	23.50	7626	2.05	.021	0	216178	551	184367	111261	223499	626	223371	12.106	.65	5.581
296	5.20	64913	65.73	23.50	7626	1.87	.021	0	221626	6601	183766	111261	223371	667	217239	12.181	.65	5.578
297	5.00				7626				215827				217239			12.388	.64	5.424

APPENDIX C

THE VELZ ALGORITHM

The Velz model of stream reaeration is employed in the routine WILMA. This estimation of atmospheric reaeration in stream flow is defined by Equations 11 to 18. Further discussion may be found in Velz's text (28).

R = Atmospheric reaeration in reach, ppd

$$= QS \left[P_{bottom} - P_{top} \right] \times 10^{-6} + \begin{bmatrix} \text{BOD} \\ \text{IOD} \\ \text{exerted} \end{bmatrix} \qquad (11)$$

$$= Y \left[1 - (P_{top} + P_{bottom})/2 \right] \qquad (12)$$

Y = Reaeration in reach initially devoid of DO, ppd

$$= \begin{bmatrix} \text{DO in} \\ \text{saturated} \\ \text{reach, lb} \end{bmatrix} \begin{bmatrix} D \end{bmatrix} \begin{bmatrix} \text{Mix} \\ \text{intervals} \\ \text{per day} \end{bmatrix}$$

$$= 62.4\ VS \times 10^{-6} \times D \times 1440/I \qquad (13)$$

D = Reaeration as percentage saturation absorbed per mix interval by water initially devoid of DO

$$= \frac{2}{30.48\ H} \left[\frac{a\ I}{\pi\ 60} \right]^{1/2}, \text{ Deininger's solution} \qquad (14)$$

a = Phelps' diffusion coefficient

$$= 1.42 \times 1.1^{(T-20)} \qquad (15)$$

I = Mix interval in reach, minutes

$$= 1.797 + 3.090\ H - 0.088\ H^2 + 0.00092\ H^3, \text{ usual freshwater streams} \qquad (16)$$

$$= 1.426 + 2.215\ H - 0.061\ H^2 + 0.00063\ H^3, \text{ tidal regimes} \qquad (17)$$

$$R = 5.12 \times 10^{-4} \times 1.1^{(T/2-10)}\ VS \left[1 - (P_{top} + P_{bottom})/2 \right] / (HI^{1/2}) \qquad (18)$$

where Q = Discharge through reach, lbs/day water
S = DO saturation, mg/l
P = Percent DO saturation as decimal
V = Reach volume, ft^3
H = Reach depth, ft
T = Reach temperature, °C

Equations 16 and 17 are empirical determinations by Velz. Equation 18 stems from Deininger's direct solution to Fick's law of diffusion,

$$\frac{\partial m}{\partial t} = - D_L A \frac{\partial c}{\partial x} \qquad (19)$$

where ∂m is the mass of oxygen passing through a cross-sectional area A in time ∂t when the concentration gradient is $\partial c/\partial x$, where oxygen concentration is c at x, and D_L is a diffusion coefficient. Equations 13 and 14 modify Phelps' theory of quiescent diffusion to account for a waterbody that is mixing.

Equations 11 and 18 may be solved simultaneously for R and P at reach bottom. Velz resorts to a graphical method, but a direct search procedure on the computer resolves the two terms rapidly.

EQUIVALENT REAERATION COEFFICIENT

The Velz reaeration algorithm is more complex than a standard oxygen sag reaeration coefficient (K_2) approach, where the reaeration rate is equal to $K_2(1 - P)$. A K_2 equivalent, a constant applied to the DO deficit in a given reach that would indicate the amount of reaeration found by the Velz procedure, was determined by computer search for each reach in the lower Willamette. Mean equivalent K_2's, base 10, were: 0.18, Salem-Newberg, 0.05, Newberg Pool, and 0.02, tidal reach.

Values of equivalent K_2's are plotted on Figure C-26. Regressing equivalent K_2 on velocity, depth (Figures C-27(a) and (b)), and stream type, a rate model resulted as:

$$K_2 = \frac{1.437\ U^{(0.160 - 0.190\ N)}}{H^{(1.122 - 0.104\ N)}} \qquad (20)$$

where K_2 = coefficient of reaeration, per day, base 10°c, 20°C,
U = velocity, fps,
N = 0, tidal regimes, below river km 43,
1, usual freshwater streams, above km 43, and
H = depth, ft.

The significant interaction of stream type, depth and velocity upon equivalent K_2 explains why standard reaeration expressions not incorporating stream type may fail to adequately model Willamette DO under low flow conditions. It is possible that a judicious selection of a K_2 reaeration model might produce the generally good fit that the Velz method provides. DO simulations using alternative K_2 expressions taken from the literature, however, yielded no single reaeration formulation that adequately modeled existing data for the Salem to Portland Willamette main stem.

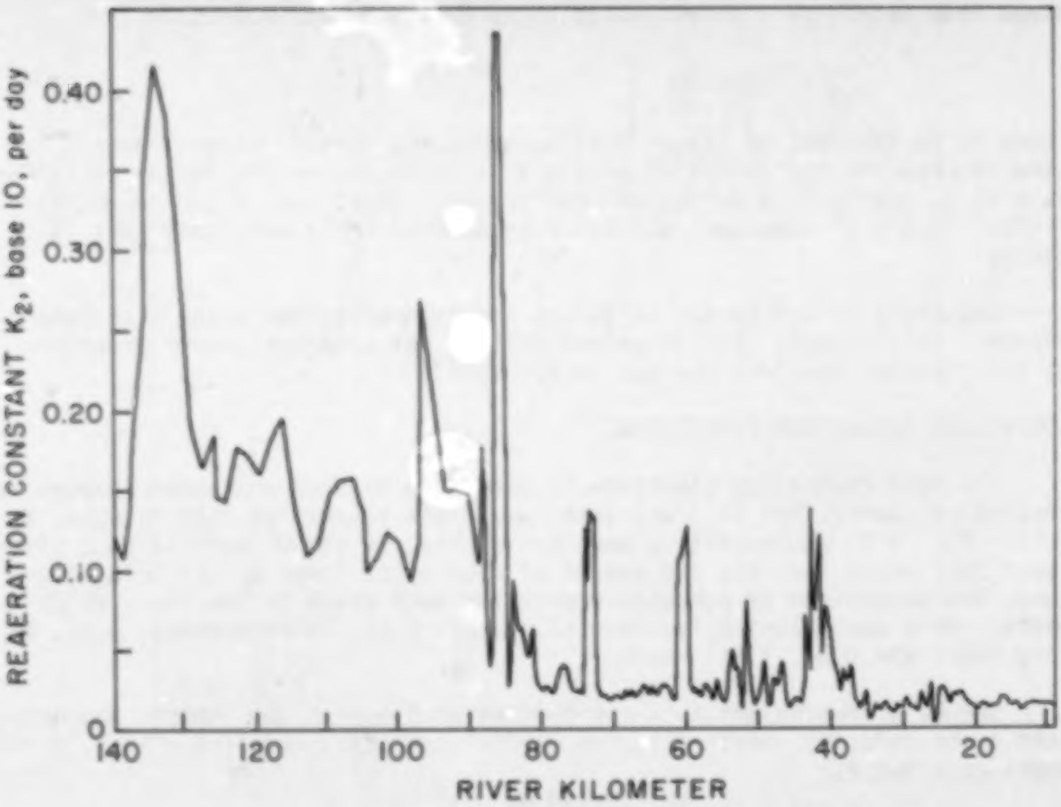

Figure C-26. Equivalent K_2 for Willamette low flow versus river kilometer.

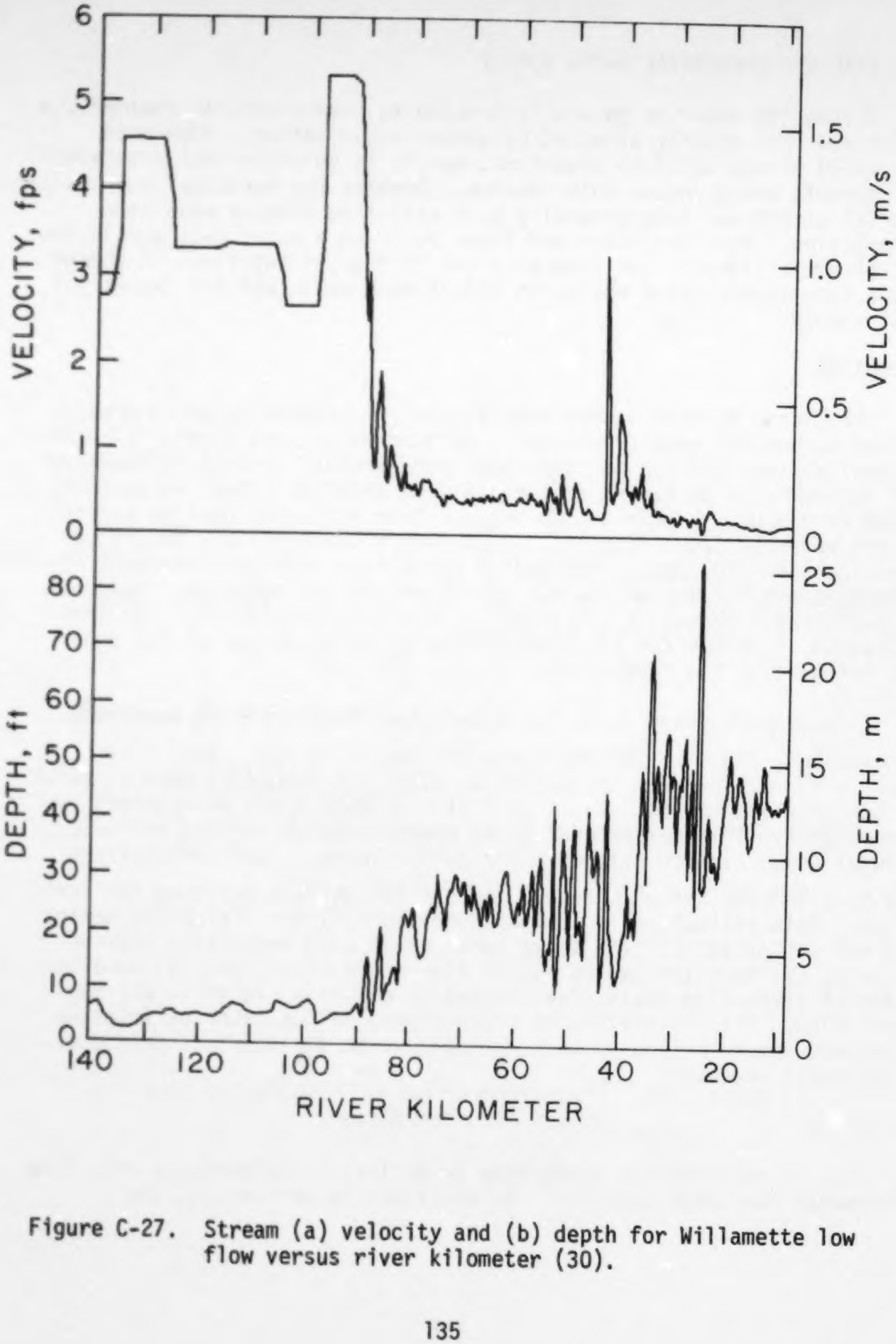

Figure C-27. Stream (a) velocity and (b) depth for Willamette low flow versus river kilometer (30).

APPENDIX D

MUNICIPAL AND INDUSTRIAL WATER SUPPLY

Willamette water is generally treated to remove natural sediment, a constituent not greatly affected by summer augmentation. Augmented flow would dilute coliform organisms, but it is unlikely that waterworks subsequently would reduce chlorination. Demands for municipal and industrial withdrawal have generally been satisfied without main stem augmentation. Municipalities and firms desiring a water less turbid than that of the Willamette can generally get it from tributaries. A change in low flow augmentation would not affect most municipal and industrial water supply.

IRRIGATION

Irrigation benefit is not significantly increased by water quality as long as quality remains aerobic. As long as present rights for agricultural abstraction are not impinged upon, present irrigation benefits will not decrease by having Willamette flow altered. There is current belief in the DEQ, however, that augmentation for water quality control may not have the legal right to usurp river flow divertable to irrigation expansion (10, 86). This belief stems from original reservoir authorizations for irrigation but not water quality benefits. Much of the augmented flow thus might properly belong to the farmers. If this is assumed, flow for quality augmentation might be valued at the benefits foregone by the irrigators.

In a typical year, main stem flow below the Santiam is augmented approximately 120 m^3/s for the 5-month drawdown season. Were this water to be employed for irrigation at \$5/af net return (a typical value for row crops in the Valley), a \$6.5 million gain would be realized by farmers (87). This corresponds to an approximate 10 percent increase in total production on all Basin irrigation lands. Such assumptions lead to a \$53 000 per m^3/s annual benefit for uniform drawdown for irrigation. This estimation is a high bound, for (1) the irrigation demand does not yet exist, (2) the value added would show decreasing returns to scale, (3) some irrigation return flow would occur, and (4) no allocation of streamflow would give irrigators complete rights to all augmented flow. This estimation of price, then, values water by imposing an assumed future policy of water management on a historical record of agricultural economics.

NAVIGATION

Flow maintenance for navigation is entirely complementary with flow maintenance for other benefits. As mentioned in Section IV, the

Willamette is decreasingly used for commercial transportation. Channel depth through Portland Harbor is more regulated by the tidal Columbia than by Willamette discharge. There is little economic evidence to suggest that total annual navigation use significantly depends upon summer low flow discharge. Navigation and channel maintenance are insensitive to DO quality.

HYDROELECTRIC POWER

A hydroelectric power cost or benefit attributable to low flow augmentation may be determined from augmentation's effect on through-turbine discharge, reservoir head, and the temporal pattern of generation. Figure D-28 traces (a) the mean head for powerhouses at multipurpose Willamette reservoirs; (b) total discharge from those reservoirs, partitioned into over-spillway and through-turbine flow; and (c) total net generation from those projects. Head is highest in the early summer. Water is spilled generally in the autumn. Generation varies with both head and turbine discharge. Low flow augmentation is largely responsible for the late summer drop in powerhouse head. As spill is not wasted in this period, through-turbine flow is not foregone. If the reservoirs were maintained at full capacity throughout the summer, thus providing some slight additional head for power, more water would be spilled from fall runoff, thus lost to power. Given that the reservoirs must be lowered for winter flood control, annual power production is not significantly altered by the late summer releases.

The timing of Willamette power generation reflects both hydroelectric power peaking strategy for regional needs and inter-regional management. The later summer drawdown and corresponding power produced is needed in California; power is repaid during the winter season when it is locally demanded. The cost of transhipment is outweighed by efficient utilization of power plants. An altered scheme for Willamette flow augmentation would not cause net power production to be substantially altered.

FLOOD PROTECTION

Like navigation and power, flood protection is a benefit independent of water quality. Deviation above the flood control rule curve (Figure 6(a)) represents loss of flood control capacity, thus potential penalty. Deviation below the rule indicates increased flood protection, a benefit if and only if there are flood damages yet reduced by such control.

An increased late summer flow may be operationally achieved by two rule curve modifications. A full pool may be maintained later into the summer and/or a minimum pool may be realized sooner in the autumn. In each instance, a steeper rate of drawdown increases late summer augmentation. The full pool held longer into the summer might decrease summer flood protection. Hydrologically, the Willamette is not apt to flood in this season. If it were to do so, normal rule allowance would compensate. A low pool earlier in the fall, another consequence of in-

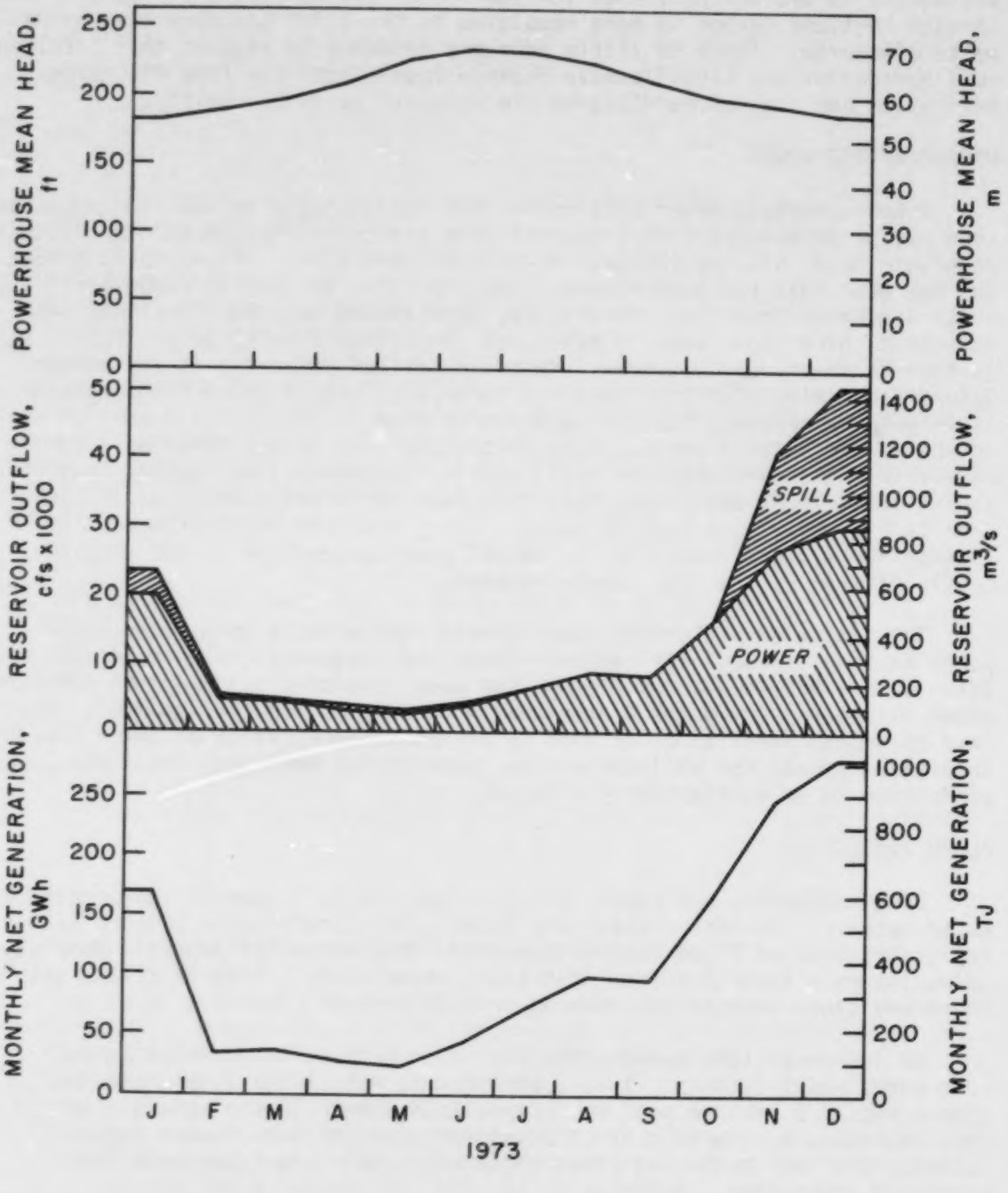

Figure D-28. Powerhouse head, reservoir outflow, and (c) generation, 1973 (88).

creased summer augmentation, may provide additional capacity for flood storage from early winter storms. This benefit, however, is not likely to be realized. Damaging floods commonly result from lack of total reservoir capacity, not inability to empty storage before the flood season.

RECREATION

Any policy of reservoir storage and release will have recreation impact. Recreation response to a program of main stem flow augmentation for quality control might include (1) increased downstream water-contact summer recreation, (2) increased downstream boating, (3) decreased water-edge reservoir recreation during the drawdown season, and (4) a decreased reservoir boating season. Whereas all four responses may occur in the case of the Willamette, any net annual impact of reservoir releases tends to cancel. Reservoir recreational visits by annual count do not seem to depend on drawdown. Recreation's insensitivity to reservoir drawdown is indicated by other studies (89). Undoubtedly, drawdown leads to changed patterns of recreation activities, but on the whole, no net gain or loss is foreseen to result from augmented main stem summer flow.

WASTE DISPOSAL

The ability of a river to satisfactorily carry away waste products is directly related to both discharge and receiving water quality. The greater the discharge, the faster the water's velocity, and the sooner the wastes will be flushed downstream. The greater the discharge, the more wastes will be diluted and the less problems of concentration they will create. The higher the water quality, the more assimilative capacity exists to biodegrade waste products. This study deals with estimating the waste disposal benefits of low flow augmentation. Such benefits therefore cannot be independently given, but rather are determined in Section IX.

FISH AND WILDLIFE

The return of fish to the Willamette has been shown to correspond to the river's cleanup. A loss of such a resource must carry with it a substantial regional economic penalty. In this study, however, it is not necessary to estimate the quantative nature of such a price. Any environmental strategy leaving the summer low flow with insufficient oxygen for fish passage is objectionable, thus not allowed. Natural obstructions and low flow hinder natural fish passage if limiting water quality levels are not violated. Credit for improvement upon passage, if allowed, should be given to the ladder at Willamette Falls, not the augmented level of flow itself.

APPENDIX E

METHOD

Methods for cost allocation are documented elsewhere (50). The method of allocation employed here is the separable costs-remaining benefit method, modified for equity. The equity modification is in compliance with Federal Inter-Agency River Basin Committee and Bureau of the Budget objectives for cost allocation procedures (51. The cost allocation procedure is as follows.

T = Multiple-purpose total project cost

S_x = Separable cost of purpose x

$N = T - \Sigma S$ = Total nonseparable costs

B_x = Benefits to purpose x

A_x = Alternative project cost for purpose x

$J_x = \min(A_x, B_x)$ = Justifiable cost of x

$O_x = \min(T-S_x, \Sigma J - J_x)$ = Justifiable costs combining all other purposes

$E_x = (O_x + J_x)/T$ = Correction for equity

$R_x = J_x - E_x S_x$ = Adjusted remaining benefit to x

$N_x = N \times R_x/\Sigma R$ = Adjusted nonseparable costs allocated to x

$T_x = S_x + N_x$ = Total cost allocated to x

Separable costs, S_x, are those expenses incurred solely in support of one project purpose, x. For a multipurpose project, total project cost, T, less separable costs yields the nonseparable remainder, N. Justifiable cost of a project purpose, J_x is the lesser of the benefit, B_x, afforded by purpose x, or the alternative cost, A_x, of obtaining that benefit from some other project. Justifiable cost combining all other project purposes, O_x, is the lesser of the cost of a project combining all purposes but purpose x, or the sum of all other justifiable single purpose costs.

Correction for equity, E_x, an allowance for fair distribution of cost savings to all project purposes, is obtained by adding justifiable single purpose cost to justifiable costs combining all other purposes and dividing by the total project cost. This allows each project purpose a savings proportional to the savings from inclusion of that purpose in the project. Without such correction, all project savings accrue entirely to nonseparable costs.

Adjusted remaining benefit, R_x, is the justifiable cost of a purpose less the separable cost of that purpose, corrected for equity. Adjusted nonseparable cost, N_x, is the portion of total nonseparable costs determined by the ratio of adjusted remaining benefit of a purpose to the total adjusted remaining benefits. Total cost allocated to a purpose, T_x, is the appropriate separable cost and adjusted nonseparable cost.

WILLAMETTE RESERVOIRS

The cost of Willamette multipurpose reservoirs allocated to water quality control may be simplified if two observations are made about the Willamette system. First, all projects are so extensively designed for flood control that no additional expenses are incurred for a program of summer release for whatever purpose. Secondly, augmentation benefits other than water quality have either lost much of their dollar significance (e.g. navigation) or may be thought of as not a co-equal benefit with water quality, but a benefit subsequently spunoff from water quality (e.g. fish and wildlife or recreation).

Flood control and hydroelectric power are project purposes, duly authorized and affording independent benefits. Municipal, industrial, and irrigation withdrawal benefits are assumed to be negligible if summer reservoir drawdown is left instream for flow augmentation. The remaining benefits (navigation, recreation, waste disposal, and fish and wildlife enhancement) are related to low flow maintenance, subsumed in the benefit of water quality control. Thus the multipurpose reservoirs provide three significant services: flood control (FC) hydroelectric power (HP), and water quality (WQ).

Table E-25 illustrates cost allocation for Basin reservoirs. Note that flood control benefits alone justify the entire project. Revenues from hydroelectricity just pay separable costs; hydroelectric power realizes no excess benefits with which to pay for nonseparable expenses. Were the value of power doubled while expenses held constant, costs would be allocated as shown in Table E-26. The cost allocated to water quality might drop several percent, a modification probably minor when compared to the imprecision in estimates for flood control returns upon which water quality charges also depend.

TABLE E-25. WILLAMETTE MULTIPURPOSE RESERVOIRS COST ALLOCATION
($\$ \times 10^6$/yr, 1973)*

Item		Hydropower	Flood Control	Water Quality	Total
Total Cost	T				45
Separable Cost	S	18	0	0	18
Nonseparable Cost	N				27
Alternative Cost	A	18	>98	Unknown	
Benefit	B	18	98	A_{WQ}	
Justifiable Cost	J	18	98	A_{WQ}	
Other Purposes	O	27	$\min\begin{cases}45\\18 + A_{WQ}\end{cases}$	45	
Equity	E	1.000	$(98 + O_{FC})/45$	$1 + A_{WQ}/45$	
Remaining Benefit	R	0	98	A_{WQ}	$98 + A_{WQ}$
Nonseparable Cost	N	0	$\frac{2678}{98 + A_{WQ}}$	$\frac{27\ A_{WQ}}{98 + A_{WQ}}$	
Total Cost	T	18			45

*Entries rounded to integer value

TABLE E-26. WILLAMETTE MULTIPURPOSE RESERVOIRS COST ALLOCATION
($ x 10^6/yr, 1973)*
Doubled 1973 Power Revenues

Item		Hydropower	Flood Control	Water Quality	Total
Total Cost	T				45
Separable Cost	S	18	0	0	18
Nonseparable Cost	N				27
Alternative Cost	A	36	>98	Unknown	
Benefit	B	36	98	A_{WQ}	
Justifiable Cost	J	36	98	A_{WQ}	
Other Purposes	O	27	$\min\begin{cases}45\\36 + A_{WQ}\end{cases}$	45	
Equity	E	1.397	$(98 + O_{FC})/45$	$1 + A_{WQ}/45$	
Remaining Benefit	R	11	98	A_{WQ}	$109 + A_{WQ}$
Nonseparable Cost	N	$\frac{295}{109 + A_{WQ}}$	$\frac{2678}{109 + A_{WQ}}$	$\frac{27 A_{WQ}}{109 + A_{WQ}}$	
Total Cost	T	$18 + \frac{295}{109 + A_{WQ}}$			45

*Entries rounded to integer value

APPENDIX F

MODEL DEFINITION

Energy I/O modeling and economic I/O analysis are of similar nature. Because the economic model is I/O's most common employment, and because it is common to visualize dollar flow within an economy, an economic I/O example serves to both describe and illustrate the general nature of I/O analysis. An energy model is then formulated for example solution.

An Economic I/O Model

Assume a four sector economy of manufacturing (M), crude oil production (C), refined petroleum (R), and pollution control (P). Each sector in one time period, say a year, produces X_i units of output.

$$X_i = \sum_{j=1}^{n} A_{ij}X_j + Y_i \qquad (21)$$

where n = sectors of the economy, 4 in this case,

X_j = total production by sector j,

X_{ij} = output from sector i used by sector j,

A_{ij} = X_{ij}/X_j, an empirical direct activity coefficient, and

Y_i = output of i exported to final, non intrasector, demand

In the example case, X_R is the total production of, say, gasoline, X_{RP} represents the gasoline used by the pollution control sector, A_{RP} is the ratio of gasoline used in pollution control equipment production to pollution control equipment produced, and Y_R is the gasoline sold to households and government. Nonhomogenety within sectors precludes determination of the direct activity coefficients, A, as goods/good ratios. Dollar equivalents at producers prices are instead used. Thus X's and Y's are measured in dollars, A's as dimensionless fractions. Suppose dollar sales in a base year are:

	Purchaser					
Producer	M	C	K	P	Y	X
M	6	1	2	1	15	25
C	1	1	3	0	0	5
R	3	1	1	2	13	20
P	4	1	1	1	3	10

This table is known as the transaction table. The 3 in the third row represents \$3 of refined petroleum sales to the manufacturing sector. The 6 in the first row represents \$6 worth of manufactured goods sold within that same sector. The Y column is exogenous or final demand. The X column sums the row. Note that for each sector j to remain in business,

$$\sum_{i=1}^{n} X_{ij} < X_j$$

A table of direct activity coefficients is obtained by dividing the X_{ij} terms by the appropriate X_j. The resulting direct activity coefficient table is:

	Purchaser			
Purchaser	M	C	R	P
M	6/25	1/5	2/20	1/10
C	1/25	1/5	3/20	0
R	3/25	1/5	1/20	2/10
P	4/25	1/5	1/20	1/10

Thus it requires \$6/25 of machinery, \$1/25 of crude oil, \$3/25 of gas, and \$4/25 of pollution control to produce \$1 worth of machinery. In algebraic form,

$$X_M = .24\ X_M + .2X_C + .10X_R + .10X_P + Y_M \tag{22}$$

$$X_C = .04\ X_M + .2X_C + .15X_R + 0X_P + Y_C \tag{23}$$

$$X_R = .12\ X_M + .2X_C + .05X_R + .20X_P + Y_R \tag{24}$$

$$X_P = .16\ X_M + .2X_C = .05X_R + .10X_P + Y_P \tag{25}$$

In matrix form, the economy is described:

$$\underline{X} = \underline{AX} + \underline{Y} \tag{26}$$

Moving all X terms to the left, the matrix expression $(\underline{I-A})\ \underline{X} = \underline{Y}$ is obtained.

$$\begin{bmatrix} .76 & -.20 & -.10 & -.10 \\ -.04 & .80 & -.15 & 0 \\ -.12 & -.20 & .95 & -.20 \\ -.16 & -.20 & -.05 & .90 \end{bmatrix} \begin{bmatrix} X_M \\ X_C \\ X_R \\ X_P \end{bmatrix} = \begin{bmatrix} Y_M \\ Y_C \\ Y_R \\ Y_P \end{bmatrix} \tag{27}$$

To obtain X as a function of Y, total production as a function of final demand, the ($\underline{I-A}$) can be inverted and transposed.

$$\underline{X} = \underline{(I - A)}^{-1}\ \underline{Y} \tag{28}$$

Doing this to the four-sector example, "direct plus indirect" coefficients result.

$$\begin{bmatrix} X_M \\ X_C \\ X_R \\ X_P \end{bmatrix} = \begin{bmatrix} 1.422 & 0.467 & 0.234 & 0.210 \\ 0.121 & 1.354 & 0.230 & 0.065 \\ 0.267 & 0.430 & 1.164 & 0.288 \\ 0.294 & 0.408 & 0.157 & 1.179 \end{bmatrix} \begin{bmatrix} Y_M \\ Y_C \\ Y_R \\ Y_P \end{bmatrix} \tag{29}$$

The values in the fourth row indicate the dollar increase in pollution control production necessary to allow a $1 increase in final demand from each column sector. Note that an additional $0.179 of interindustrial pollution control is needed to provide a dollar's worth of pollution control export in this example. Total outputs can now be determined necessary to satisfy both internal and external requirements of an arbitrary set of final demands. For the U.S. economy, $\underline{(I - A)}^{-1}$, the direct plus indirect coefficients, have been determined for 1967 (92).

An Energy I/O Model

To this point, units have had monetary basis. The same model can likewise be applied to energy flow, say in joule units. The designator E can be used in similar fashion to the previous X.

$$E_i = \sum_{k=1}^{n} E_{ik} + E_{iy} \tag{30}$$

where E_i = total energy output of sector i,

E_{ik} = energy output by sector i used by sector k, and

E_{iy} = energy output by sector i sold to final demand.

Recall that,

$$X_k = \sum_{j=1}^{n} (I-A)^{-1}_{kj} \; Y_j \tag{31}$$

Multiplying E_{ik} by X_k/X_k,

$$E_{ik} = \frac{E_{ik}}{X_k} \sum_{j=1}^{n} (I-A)^{-1}_{kj} \; Y_j \tag{32}$$

Then,

$$E_i = \sum_{k=1}^{n} \left[\frac{E_{ik}}{X_k} \sum_{j=1}^{n} (I-A)^{-1}_{kj} \; Y_j \right] + \left(\frac{E_{iy}}{Y_i}\right) Y_i . \tag{33}$$

Define $R_{ik} = E_{ik}/X_k$, the energy component from sector i in a dollar of k production, and

S_i = the producer's price for energy sold to final demand

$= E_{iy}/Y_i$, i = energy sector

0, otherwise.

Combining terms in matrix form.

$$\underline{E} = [\underline{R} \; \underline{(I-A)}^{-1} + \underline{S}] \; \underline{Y} \tag{34}$$

As was $\underline{X}$ in dollars, $\underline{E}$ is the production of energy required both directly and indirectly to satisfy a final demand, $\underline{Y}$. Note that $\underline{R}$ is an empirical factor of production, $(\underline{I-A})^{-1}$ has been previously determined, and $\underline{S}$ is another empirical value. The bracketed term $[\underline{R}(\underline{I-A})^{-1} + \underline{S}]$ may be designated $\underline{\varepsilon}$, the total energy matrix. Returning to the four-sector example, assume the following table of joule sales has been obtained from industrial records.

	Purchaser					
Producer	M	C	R	P	Y	X
M	0	0	0	0	0	0
C	2	1	37	0	0	40
R	5	1	2	1	16	25
P	0	0	0	0	0	0

Unlike the dollar requirement of viability, only the crude oil sector appears to produce a net energy. This sector, of course, achieves its 40 to 2 energy increase by drawing upon "free" input from the environment. Refined petroleum dollar and energy outputs are not necessarily proportional. Different energy pricing is allowed. The $\underline{R}$ matrix eliminates the non-energy rows, M and P.

$$\underline{R} = \begin{bmatrix} 2/25 & 1/5 & 37/20 & 0 \\ 5/25 & 1/5 & 2/20 & 1/10 \end{bmatrix} \tag{35}$$

Thus,

$$\underline{c} = \begin{bmatrix} .08 & .2 & 1.85 & 0 \\ .2 & .2 & .1 & .1 \end{bmatrix} \begin{bmatrix} 1.422 & 0.467 & 0.234 & 0.210 \\ 0.121 & 1.354 & 0.230 & 0.065 \\ 0.267 & 0.430 & 1.164 & 0.288 \\ 0.294 & 0.408 & 0.157 & 1.179 \end{bmatrix}$$

$$+ \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 16/13 & 0 \end{bmatrix}$$

$$= \begin{bmatrix} 0.632 & 1.103 & 2.218 & 0.563 \\ 0.365 & 0.448 & 1.456 & 0.202 \end{bmatrix} \tag{36}$$

From this example matrix, it is seen that $1 final demand of pollution control requires 0.563 joules of production from the crude oil sector and 0.202 joules from the refined petroleum sector. The two values should not be summed, however, or a double counting of energy occurs.

THE PROBLEM OF DOUBLE COUNTING

When I/O is applied to dollar-only problems, columns of the $(\underline{I-A})^{-1}$ matrix are often summed to obtain the overall dollar flow response to unit of exogeneous demand. Summing the fourth column in the example $(\underline{I-A})^{-1}$ matrix, $1.742 of total production is generated by $1 final demand for pollution control. Such vertical summation is proper where one dollar, passing through two hands, can be interpreted as having twice the economic impact as it would have had, had that dollar only passed through one hand.

Such addition is not proper for energy analysis. Unlike a dollar, a joule spent is a joule not to be spent again. In the example, two energy sectors provide joules for pollution control. But all the joules produced by the refining industry are transformed primary joules of crude oil. No energy is produced in refinement; energy quality is upgraded. From the viewpoint of resource management, the use of refined petroleum is of internal, not external, economic consequence. That which sustains the economy is primary input to the overall system, not the technology of energy circulation within. In this example, the primary requirement necessary for pollution control is 0.563 joules mined by the crude oil sector.

The problem of double counting can be illustrated by adding to the example model another sector, say one of refined petroleum transport, T. This activity can be thought of as before having been incorporated in the refining sector itself. The direct joule table adds row and column T. Let all 25 joules produced in R now go to T. These 25 are distributed by T as they were before by R. From an external viewpoint, the system behaves exactly as before. From the viewpoint of internal circulation there is a new step, more transfer, and an additional total energy coefficient. Adding these coefficients for $1 of pollution control final demand, joule flow seems to be greater. The more numerous the economic partitions, the more interindustrial circulation results and the greater will be the total direct-plus-indirects. The net efficiency of the system, the cost of stock energy per unit of goods production, must only consider the primary coefficients relevant to external inputs. In this example, the primary energy requirement for $1 worth of P final demand is 0.563 joules.

The only example of direct energy demand by final demand is that of refined petroleum. Sixteen joules are exported for $13. In common energy usage, the term "direct" has a different meaning. Direct energy is the fuel value consumed in the final step of production, not the value of the fuel supplied to final, non-industrial, demand. The common usage of "direct" leads to 7/25, 2/5, 39/20, and 1/10 joules of crude and refined petroleum burned per dollar output of each sector. Values such as these correspond to energy estimates used in direct energy analysis of water pollution control strategy. These direct energy coefficients indicate the immediate, local demand for pollution control energy. The primary coefficients indicate the overall impact on the fossil reserves.

Table F-27 illustrates the two interpretations of direct energy and the primary requirement for the example economy. The first column is of interest only for sectors selling energy outside the industrial matrix. Table 9 in Section VIII lists the direct-for-production and primary energy I/O coefficients for various sectors participating in pollution control activity. In effect, Table 9 is a real-value partitioning of the bottom illustrative line in Table F-27.

TABLE F-27. INPUT/OUTPUT DIRECT AND PRIMARY ENERGY COEFFICIENTS (J/dollar final demand)

Sector	Sales to final demand	Direct for production	Primary
M	0	0.280	0.632
C	0	0.400	1.103
R	1.231	1.950	2.218
P	0	0.100	0.563

APPENDIX G

This appendix describes the formulation of Table 10. See that table for abbreviation key.

Treatment Level A - All 1973 municipal plants are in operation, but downgraded to L if L, ASP, or ASPL in 1973, to P otherwise. All but two industrial dischargers release 7.5 times 1973 BOD and Kjeldahl N. The two exceptions reflect two major 1973 N discharges assumed to be uncontrolled. Benthic and non-point demands are those of 1973.

Treatment Level B - As above, but industrial releases are three times those of 1973.

Treatment Level C - As above, but P plants are replaced by AS or TF, as indicated in 1973. Industrial releases are 1.5 times those of 1973.

Treatment Level D - August 1973 conditions.

Treatment Level E - Seven municipal plants are upgraded, three plants added, twenty-four plants abandoned, fourteen plants halt August discharge to river, and trunk sewers are added to regionalize areas with abandoned plants, all as recommended by DEQ. Industrial releases are 0.8 those of 1973. One sixth of the benthic demand is removed by regulation of Portland Harbor sewage overflows, ship discharges, dredging, gravel mining, and prop wash. Non-point sources are unchanged.

Treatment Level F - As above, but all plants are upgraded to ASEF, TFEF, or ASPL. ASP is allowed in place of ASPL only if downstream nitrification does not occur.

Treatment Level G - As above, but two industrial major N sources are reduced to 0.1 of 1973 loadings.

Treatment Level H - All municipal and industrial loadings are removed. As economic and energy models employed for levels A-G are not suited for this option, a rough dollar and joule estimation is drawn from costs projected of national leglislation directed toward elimination of point source pollution. Willamette costs are estimated to be one-third the national per capita figure, as the Willamette wastes are treatable by proven methods, (93).

TABLE H-28. WILLAMETTE BASIN WASTEWATER TREATMENT
SUMMARY OF DOLLAR AND ENERGY COSTS
Treatment Level A

COSTS	DIRECT DOLLARS Million 1973 Dollars				DIRECT ENERGY Terra Joules			PRIMARY ENERGY Terra Joules		
Variable Costs	CAPITAL	ANNUALIZED CAPITAL	OMR	TOTAL ANNUAL	CONST.	OMR	TOTAL ANNUAL	CONST.	OMR	TOTAL ANNUAL
Municipal Discharges										
Treatment Plants	41.853	3.649	2.306	5.955	410.578	120.166	140.695	2447.982	207.332	329.732
IOFLS	38.902	2.585	.321	2.906	559.800	16.727	30.722	1525.736	28.861	67.005
Industrial Pretreatment	.398	.044	.372	.416	3.904	13.146	13.303	23.279	30.214	31.145
Industrial Discharges	3.177	.373	.139	.512	31.166	4.912	6.471	185.823	11.290	20.581
Total	84.330	6.651	3.138	9.789	1005.448	154.952	191.190	4182.828	277.697	448.462
Fixed or Independent Costs										
Municipal Discharges										
Treatment Plants	11.652	1.016	.642	1.658	114.306	33.455	39.170	681.525	57.722	91.798
IOFLS	50.673	3.368	.418	3.786	729.194	21.782	40.012	1987.395	37.582	87.267
Industrial Pretreatment	.145	.016	.094	.110	1.422	3.322	3.379	8.481	7.635	7.974
Industrial Discharges	2.094	.246	.122	.368	20.542	4.311	5.339	122.478	9.909	16.033
Abandoned Facilities	5.830	.429	0	.429	57.192	0	2.860	340.997	0	17.050
Total	70.394	5.074	1.276	6.350	922.647	62.870	90.759	3140.876	112.848	220.122
Total	154.724	11.726	4.414	16.140	1928.096	217.822	281.949	7323.697	390.545	668.584

TABLE H-29. WILLAMETTE BASIN WASTEWATER TREATMENT

SUMMARY OF DOLLAR AND ENERGY COSTS

Treatment Level B

COSTS	DIRECT DOLLARS Million 1973 Dollars				DIRECT ENERGY Terra Joules			PRIMARY ENERGY Terra Joules		
Variable Costs	CAPITAL	ANNUALIZED CAPITAL	OMR	TOTAL ANNUAL	CONST.	OMR	TOTAL ANNUAL	CONST.	OMR	TOTAL ANNUAL
Municipal Discharges										
Treatment Plants	41.853	3.649	2.306	5.955	410.578	120.166	140.695	2447.982	207.332	329.732
IOFLS	38.902	2.585	.321	2.906	559.800	16.727	30.722	1525.736	28.861	67.005
Industrial Pretreatment	.398	.044	.372	.416	3.904	13.146	13.303	23.279	30.214	31.145
Industrial Discharges	23.417	2.751	1.027	3.778	229.721	36.294	47.780	1369.660	83.413	151.896
Total	104.570	9.029	4.026	13.055	1204.003	186.334	232.500	5366.658	349.820	579.777
Fixed or Independent Costs										
Municipal Discharges										
Treatment Plants	11.652	1.016	.642	1.658	114.306	33.455	39.170	681.525	57.722	91.798
IOFLS	50.673	3.368	.418	3.786	729.184	21.782	40.012	1987.395	37.582	87.267
Industrial Pretreatment	.145	.016	.094	.110	1.422	3.322	3.379	8.481	7.635	7.974
Industrial Discharges	2.094	.246	.122	.368	20.542	4.311	5.339	122.478	9.909	16.033
Abandoned Facilities	5.830	.429	0	.429	57.192	0	2.860	340.997	0	17.050
Total	70.394	5.074	1.276	6.350	922.647	62.870	90.759	3140.876	112.848	220.122
Total	174.964	14.103	5.302	19.405	2126.650	249.204	323.258	8507.534	462.668	799.899

TABLE H-30. WILLAMETTE BASIN WASTEWATER TREATMENT

SUMMARY OF DOLLAR AND ENERGY COSTS

Treatment Level C

COSTS	DIRECT DOLLARS Million 1973 Dollars				DIRECT ENERGY Terra Joules			PRIMARY ENERGY Terra Joules		
Variable Costs	CAPITAL	ANNUALIZED CAPITAL	OMR	TOTAL ANNUAL	CONST.	OMR	TOTAL ANNUAL	CONST.	OMR	TOTAL ANNUAL
Municipal Discharges										
Treatment Plants	65.366	5.699	2.935	8.634	641.248	152.943	185.005	3823.257	263.886	455.049
IOFLS	38.982	2.585	.321	2.906	559.800	16.727	30.722	1525.736	28.861	67.005
Industrial Pretreatment	.621	.068	.329	.397	6.092	11.627	11.871	36.322	26.721	28.174
Industrial Discharges	58.378	6.856	2.560	9.416	572.610	90.470	119.101	3414.061	207.923	378.626
Total	163.259	15.209	6.145	21.354	1779.742	271.767	346.699	8799.377	527.392	928.854
Fixed or Independent Costs										
Municipal Discharges										
Treatment Plants	11.692	1.016	.523	1.539	114.306	27.254	32.969	681.525	47.023	81.099
IOFLS	50.673	3.368	.418	3.786	729.186	21.782	40.012	1987.395	37.502	87.267
Industrial Pretreatment	.105	.016	.076	.092	1.422	2.686	2.743	8.481	6.173	6.512
Industrial Discharges	2.894	.246	.122	.368	20.542	4.311	5.339	122.478	9.989	16.033
Abandoned Facilities	5.030	.429	0	.429	57.192	0	2.860	340.997	0	17.050
Total	70.394	5.074	1.139	6.213	922.647	56.033	83.921	3140.876	100.687	207.961
Total	233.653	20.283	7.284	27.567	2702.389	327.800	430.620	11940.254	628.078	1136.815

TABLE H-31. WILLAMETTE BASIN WASTEWATER TREATMENT

SUMMARY OF DOLLAR AND ENERGY COSTS

Treatment Level D

COSTS	DIRECT DOLLARS Million 1973 Dollars				DIRECT ENERGY Terra Joules			PRIMARY ENERGY Terra Joules		
	CAPITAL	ANNUALIZED CAPITAL	OMR	TOTAL ANNUAL	CONST.	OMR	TOTAL ANNUAL	CONST.	OMR	TOTAL ANNUAL
Variable Costs										
Municipal Discharges										
Treatment Plants	67.194	5.858	3.180	9.038	659.173	165.711	198.670	3930.177	285.916	482.425
IOFLS	38.903	2.585	.321	2.906	559.814	16.728	30.723	1525.774	28.862	67.006
Industrial Pretreatment	.639	.070	.357	.428	6.270	12.631	12.882	37.384	29.030	30.525
Industrial Discharges	71.200	8.363	3.123	11.486	698.472	110.360	145.284	4164.488	253.634	461.859
Total	177.936	16.877	6.981	23.858	1923.729	305.430	387.559	9657.823	597.442	1041.815
Fixed or Independent Costs										
Municipal Discharges										
Treatment Plants	11.653	1.016	.551	1.567	114.312	28.735	34.451	681.562	49.580	83.658
IOFLS	50.674	3.368	.418	3.786	729.192	21.789	40.019	1987.415	37.594	87.280
Industrial Pretreatment	.145	.016	.081	.097	1.423	2.866	2.923	8.484	6.588	6.927
Industrial Discharges	2.894	.246	.123	.369	20.544	4.347	5.374	122.489	9.990	16.114
Abandoned Facilities	5.038	.429	0	.429	57.192	0	2.860	340.997	0	17.050
Total	70.395	5.075	1.174	6.248	922.663	57.738	85.627	3140.947	103.752	211.029
Total	248.331	21.952	8.155	30.107	2846.392	363.168	473.185	12798.770	701.194	1252.844

TABLE H-32. WILLAMETTE BASIN WASTEWATER TREATMENT
SUMMARY OF DOLLAR AND ENERGY COSTS
Treatment Level E

COSTS	DIRECT DOLLARS Million 1973 Dollars				DIRECT ENERGY Terra Joules			PRIMARY ENERGY Terra Joules		
	CAPITAL	ANNUALIZED CAPITAL	OMR	TOTAL ANNUAL	CONST.	OMR	TOTAL ANNUAL	CONST.	OMR	TOTAL ANNUAL
Variable Costs										
Municipal Discharges										
Treatment Plants	73.806	6.441	3.667	10.108	724.822	191.087	227.328	4321.592	329.700	545.780
IOFLS	58.282	3.868	.480	4.348	837.527	25.013	45.951	2282.682	43.157	100.224
Industrial Pretreatment	.703	.077	.413	.490	6.896	14.595	14.871	41.118	33.544	35.189
Industrial Discharges	79.426	9.329	3.483	12.812	779.169	123.089	162.048	4645.627	282.889	515.171
Total	212.217	19.716	8.043	27.759	2348.414	353.785	450.198	11291.020	689.290	1196.363
Fixed or Independent Costs										
Municipal Discharges										
Treatment Plants	12.487	1.089	.621	1.710	122.497	32.360	38.485	730.365	55.834	92.352
IOFLS	58.673	3.368	.418	3.786	729.104	21.792	40.812	1987.395	37.582	87.267
Industrial Pretreatment	.155	.017	.091	.108	1.521	3.216	3.277	9.666	7.391	7.754
Industrial Discharges	2.094	.246	.122	.368	20.542	4.311	5.339	122.478	9.909	16.033
Abandoned Facilities	25.994	1.913	0	1.913	255.081	0	12.752	1520.389	0	76.019
Total	91.403	6.632	1.252	7.884	1128.746	61.670	99.862	4369.693	110.716	279.425
Total	303.620	26.348	9.295	35.643	3477.160	415.455	550.061	15660.713	800.006	1475.788

TABLE H-33. WILLAMETTE BASIN WASTEWATER TREATMENT

SUMMARY OF DOLLAR AND ENERGY COSTS

Treatment Level F

COSTS	DIRECT DOLLARS Million 1973 Dollars				DIRECT ENERGY Terra Joules			PRIMARY ENERGY Terra Joules		
	CAPITAL	ANNUALIZED CAPITAL	OMR	TOTAL ANNUAL	CONST.	OMR	TOTAL ANNUAL	CONST.	OMR	TOTAL ANNUAL
Variable Costs										
Municipal Discharges										
Treatment Plants	82.844	7.222	4.521	11.743	812.708	235.589	276.224	4965.546	486.483	640.763
IOFLS	59.282	3.868	.480	4.348	837.527	25.013	45.951	2262.682	43.157	108.226
Industrial Pretreatment	.788	.087	.508	.595	7.730	17.953	18.262	46.090	41.260	43.103
Industrial Discharges	79.426	9.329	3.483	12.812	779.169	123.089	162.048	4645.627	202.889	515.171
Total	221.268	20.507	8.992	29.499	2437.126	401.644	502.485	11919.945	773.789	1307.258
Fixed or Independent Costs										
Municipal Discharges										
Treatment Plants	12.487	1.089	.681	1.770	122.497	35.487	41.612	730.365	61.229	97.747
IOFLS	50.673	3.368	.418	3.786	729.146	21.782	40.012	1987.395	37.582	87.267
Industrial Pretreatment	.155	.017	.100	.117	1.521	3.534	3.595	9.066	5.122	5.455
Industrial Discharges	2.094	.246	.122	.368	20.542	4.311	5.339	122.478	9.989	16.833
Abandoned Facilities	25.994	1.913	0	1.913	255.881	0	12.750	1520.389	0	76.019
Total	91.403	6.632	1.321	7.953	1129.746	65.114	103.307	4369.693	116.042	285.551
Total	312.663	27.139	10.313	37.452	3565.872	466.750	605.792	16189.638	890.631	1592.809

TABLE H-34. WILLAMETTE BASIN WASTEWATER TREATMENT

SUMMARY OF DOLLAR AND ENERGY COSTS

Treatment Level G

COSTS	DIRECT DOLLARS Million 1973 Dollars				DIRECT ENERGY Terra Joules			PRIMARY ENERGY Terra Joules		
Variable Costs	CAPITAL	ANNUALIZED CAPITAL	OMR	TOTAL ANNUAL	CONST.	OMR	TOTAL ANNUAL	CONST.	OMR	TOTAL ANNUAL
Municipal Discharges										
Treatment Plants	82.846	7.222	4.521	11.743	812.700	235.589	276.224	4845.546	406.483	648.760
IOFLS	59.282	3.868	.480	4.348	837.527	25.013	45.951	2282.682	43.157	100.224
Industrial Pretreatment	.788	.087	.508	.595	7.730	17.953	18.262	46.090	41.260	43.103
Industrial Discharges	83.061	9.850	3.837	13.687	822.676	135.600	176.733	4905.030	311.641	556.893
Total	225.695	21.028	9.346	30.374	2480.633	414.154	517.171	12079.348	802.541	1348.980
Fixed or Independent Costs										
Municipal Discharges										
Treatment Plants	12.487	1.089	.681	1.770	122.497	35.487	41.612	730.365	61.229	97.747
IOFLS	50.673	3.368	.418	3.786	729.186	21.782	40.012	1987.395	37.582	87.267
Industrial Pretreatment	.155	.017	.100	.117	1.521	3.534	3.595	9.066	8.122	8.485
Industrial Discharges	2.094	.246	.122	.368	20.542	4.311	5.339	122.478	9.909	16.033
Abandoned Facilities	25.994	1.913	0	1.913	255.001	0	12.750	1520.389	0	76.019
Total	91.403	6.632	1.321	7.953	1128.746	65.114	103.307	4369.693	116.842	285.551
Total	317.098	27.660	10.667	38.327	3609.379	479.269	620.477	16449.041	919.383	1634.531

APPENDIX I

The Input/Output estimation of primary energy cost may be particularly useful for future hydroelectric projects, capital intensive endeavors that are not infrequently challenged as costing more than they will ever produce. Traditionally, dollar benefit/cost analysis is used to resolve such an issue. A calculation of energy benefit/cost ratio might serve decision analysis in an energy-conscious society much as the dollar ratio is used when social goals are dollar production. The Willamette Basin Corps of Engineers reservoirs serve as an example case.

Five hydroelectric projects, nameplate generating capacity of 409.4 MW, net annual load factor of 44 percent, generated 1.56 TWh in 1973. Power-allocated construction costs in 1973 dollars of these projects was $420 million. Annual power production expenses were $1.267 million. The average annual cost for replacement of major components was $2.75 million.

The primary energy intensity for reservoir construction is 38 650 Btu per dollar. Therefore, construction primary energy cost for the five projects is:

$$\$420 \times 10^6 \times 38\,650 \text{ Btu/\$} = 1.62 \times 10^{13} \text{ Btu} \qquad (36)$$

If the expected project life is 100 years and the ratio of primary energy to unit job is fixed (energy and construction prices may vary, however), the average annual primary energy required for construction is 1.62×10^{11} Btu.

Assuming capital replacement has the same energy intensity as does capital construction, the average annual primary energy cost of major replacement is:

$$\$2.75 \times 10^6 \times 38\,650 \text{ Btu/\$} = 1.06 \times 10^{11} \text{ Btu} \qquad (37)$$

An energy intensity of 29 500 Btu per dollar may be applied to production expenses.

$$\$1.27 \times 10^6 \times 29\,500 \text{ Btu/\$} = 0.37 \times 10^{11} \text{ Btu} \qquad (38)$$

The total annual primary energy cost for the five hydropower plants is thus 3.05×10^{11} Btu.

The three primary energy sources of electrical power and their primary energy to generated electricity technical coefficients are:

Coal Fired Power Plants - 2.944 Btu/Btu
Oil Fired Power Plants - 3.072 Btu/Bru
Gas Fired Power Plants - 2.887 Btu/Btu

Using a typical conversion of 2.9 Btu of primary energy to produce 1 Btu of electricity, the 3.05×10^{11} Btu primary cost of the five hydroplants, if diverted from the hydroprojects to direct thermal generation would have produced 1.05×10^{11} Btu of electrical energy.

The 1.56 billion kWWhyearly produced by the projects is equivalent to 53.24×10^{11} Btu. If the 1.05×10^{11} Btu of electrical production foregone is subtracted from this output, an average annual net output of 52.19×10^{11} Btu is derived from these projects.

An energy benefit/cost ratio may be calculated.

$$\frac{B}{C} = \frac{53.24 \times 10^{11}\ \text{Btu}}{3.05 \times 10^{11}\ \text{Btu}} = 17.46 \qquad (39)$$

As the ratio is many-fold greater than 1.0, the energy-for-energy investment in the Willamette projects is productive.

APPENDIX J

Solar Input, IN

Incident solar energy at surface, I = 17 x 10^5 Cal/m^2-yr
Basin area, A = 29.676 x 10^9 m^2
Reflection from surface, R = 0.36 incident
IN = I x A (1 - R) = 3200 x 10^{12}Cal/yr

Primary Production, PP

Net primary production, NP = 700 g/m^2-yr
Bomb calometric energy content, B = 5 Cal/g
PP = NP x A x B = 100 x 10^{12} Cal/yr

Standing Crop, Biomass, SB

Standing crop density, D = 1800 g/m^2
SB = D x A x B = 2600 x 10^{12} Cal/yr

Standing Crop, Saw Timber, ST

Standing crop, saw timber, S = 193 Tg
ST = S x B = 960 x 10^{12} Cal/yr

Economic Production, Non Saw Timber Biomass, PB

Crop harvest, H = 1.87 Tg/yr
PB = H x B = 9 x 10^{12} Cal/yr

Economic Production, Saw Timber, PT

Log production, L = 4.37 Tg/yr
PT = L x B = 21 x 10^{12} Cal/yr

Precipitation Potential Energy, P

Basin runoff, BR = 1.089 x 10^{12} ft^3/yr
Mean channel elevation above lower Willamette datum, CE = 805 ft
P = BR x CE x 62.4 lb.ft^3 = 5.47 x 10^{16} ft-lb/yr = 17 x 10^{12} Cal/yr

Hydropower Production, HP

HP = 2221 x 10^6 kWh/yr = 2 x 10^{12} Cal/yr

Petroleum Import, PI

$PI = 203 \times 10^{12}$ Btu/yr $= 51 \times 10^{12}$ Cal/yr

Electrical Import, EI

Electrical consumption, $EC = 65.68 \times IO$ Btu/yr $= 16$ TCal/yr
$EI = EC - HP = 14 \times 10^{12}$ Cal/yr

Natural Gas Import, GI

$GI = 78.28 \times 10^{12}$ Btu/yr $= 20 \times 10^{12}$ Cal/yr

Energy Consumption, C

$C = HP + EI + PI + GI = 87 \times 10^{12}$ Cal/yr

Industrial Energy Consumption, IE

$IE = 0.44\ C = 38 \times 10^{12}$ Cal/yr

Imports, M

Primary energy intensity (I/O),
Agricultural products, $AE = 9598\ \text{Cal}/\$$
Forest products, $FE = 16402\ \text{Cal}/\$$
Manufactured goods, $ME = 19156\ \text{Cal}/\$$
Services, $SE = 11417\ \text{Cal}/\$$

Imports,
Agricultural products, $AI = \$176 \times 10^{6}/\text{yr}$
Forest products, $FI = \$144 \times 10^{6}/\text{yr}$
Manufactured goods, $MI = \$920 \times 10^{6}/\text{yr}$
Services, $SI = \$950 \times 10^{6}/\text{yr}$

$M = AE \times AI + FE \times FI + ME \times MI + SE \times SI = 34 \times 10^{12}$ Cal/yr

Exports, X

Exports,
Agricultural products, $AX = \$\ 184 \times 10^{6}/\text{yr}$
Forest products, $FX = \$\ 349 \times 10^{6}/\text{yr}$
Manufactured goods, $MX = \$\ 569 \times 10^{6}/\text{yr}$
Services, $SX = \$1426 \times 10^{6}/\text{yr}$

$X = AX \times AI + FX \times FI + MX \times MI + SX \times SI = 35 \times 10^{12}/\text{yr}$

Gross Output, O

Gross output,
Agricultural products, $AG = \$\ 766 \times 10^{6}/\text{yr}$
Forest products, $FG = \$1204 \times 10^{6}/\text{yr}$

Manufactured goods , MG = \$2190 x 10^6/yr
Services , SG = \$6788 x 10^6/yr

$$O = AG \times AI + FG \times FI + MG \times MI + SG \times SI = 147 \times 10^{12} \text{ Cal/yr}$$

Industrial Consumption, IC

Consumption,
Agricultural products, AC = \$ 69 x 10^6/yr
Forest products , FC = \$ 24 x 10^6/yr
Manufactured goods , MC = \$ 66 x 10^6/yr
Services , SC = \$3503 x 10^6/yr

$$IC = AC \times AI + FC \times FI + MC \times MI + SC \times SI = 43 \times 10^{12} \text{ Cal/yr}$$

Net Production, N

$$N = O - IC = 104 \times 10^{12} \text{ Cal/yr}$$

Household Consumption, HC

$$HC = N - X + EC - IE = 118 \times 10^{12} \text{ Cal/yr}$$